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HIGH-PURITY SILICA OCCURRENCES IN PENNSYLVANIA

Samuel W. Berkheiser, Jr.

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
OFFICE OF RESOURCES MANAGEMENT
BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

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Pennsylvania Geological Survey

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PREFACE

In this reconnaissance study, the author identifies some new high-purity silica resources in Pennsylvania. The search was initially directed toward identifying natural silica that could be used as "nutrient" for an established quartz-crystal-growing industry in Pennsylvania. Other Pennsylvania silica-consuming industries, such as the molding and foundry, glass, refractories, and cement industries, and specialty consumers and producers will benefit from this description of silica resources in the Commonwealth.

Land use planners, as well as industries exploring for high-purity silica deposits, should note in particular the occurrences in Adams, Bedford, Carbon, Cumberland, Franklin, Fulton, Huntingdon, Mifflin, Monroe, Schuylkill, and Tioga Counties. The silica resources in those counties should be recognized as valuable economic assets, and land use should be designed to effect maximum future utilization. With appropriate planning, such resources can serve the best interests of all concerned with little or no adverse environmental impact.

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HIGH-PURITY SILICA OCCURRENCES IN PENNSYLVANIA

by

Samuel W. Berkheiser, Jr.

ABSTRACT

Potential high-purity silica sources from nine Paleozoic formations and six quartz veins were sampled, chemically analyzed, and described from 30 locations representing 14 counties in central and eastern Pennsylvania. Percent Al_2O_3 and Fe_2O_3 are reported for as-collected and beneficiated splits. Beneficiation consisted of hot acid baths and magnetic separation.

The largest tonnage of high-purity silica in the Commonwealth includes clastic sequences from the Cambrian Antietam, Silurian Tuscarora, and Devonian Old Port ("Oriskany") and Palmerton Formations. Of all the sedimentary deposits investigated, the Cambrian Antietam Formation generally contains the least Al_2O_3 plus Fe_2O_3 for both as-collected and beneficiated samples. A fine-aggregate stockpile from a quarry in Franklin County yielded the lowest percentage of Fe_2O_3 (190 ppm (parts per million), or 0.019 percent) of all samples tested, including quartz veins.

Quartz veins generally represent the purest, but smallest, potential resource. Large quartz veins, up to about 65 feet (20 m) in width, commonly yield Al_2O_3 values of less than 1,500 ppm (0.15 percent) and Fe_2O_3 values of less than 700 ppm (0.07 percent). Beneficiated splits commonly yield Al_2O_3 and Fe_2O_3 values of less than 100 ppm (0.01 percent) and 15 ppm (0.0015 percent), respectively.

Composite samples of silica having total Al_2O_3 plus Fe_2O_3 values of 1 percent or less include (1) all quartz veins; (2) selected samples from the Cambrian Antietam and Chickies Formations; (3) all samples from the basal portion of the Silurian Tuscarora Formation; (4) one sample from the Devonian Ridgeley Member of the Old Port Formation ("Oriskany") and all samples from the Palmerton Formation; (5) one sample from the Pocono Formation; and (6) selected samples from the Pennsylvanian lower Pottsville Group.

No as-collected samples meet typical Al_2O_3 or Fe_2O_3 analyses for lasca (raw material for synthetic quartz crystals). The Cambrian Antietam Formation is a potential new source of glass sand in Pennsylvania. An as-collected sample from this formation meets typical Fe_2O_3 analyses for white glass.

Potential sources for the manufacture of elemental silicon include beneficiated samples from the Cambrian Antietam, Silurian Tuscarora, and Devonian Old Port Formations as well as some of the larger quartz veins. The quartz veins appear to have additional chemical potential as metallurgical quartz.

The best ganister target in the Commonwealth is the Silurian basal Tuscarora Formation. Locally this sequence represents one of the purest, massive quartzites in the Commonwealth. Franklin and Fulton Counties are particularly favorable areas with respect to both minable thicknesses and purity.

The Devonian Palmerton Formation may have some potential as a coarse hydraulic-fracturing sand (proppant). Medium- to fine-grained rock sequences that have potential include the Cambrian Antietam and Devonian Old Port Formations where they are friable and/or weathered.

INTRODUCTION

PURPOSE

The initial objective of this reconnaissance investigation was to identify some of the highest quality, naturally occurring silica resources in Pennsylvania. High-purity silica, which might be usable by the industrial sector, as well as nutrient-quality silica (lasca), which might be substituted for Brazilian imports, was sought. The identification of potential resources of and uses for lower quality, higher tonnage applications was also an objective of this study.

Pennsylvania is favorably located for a majority of the silica-consuming industries, and has a long and traditional role in supplying quality silica products for the glass, refractory, molding sand, and other specialty silica industries (Fettke, 1919; Moore and Taylor, 1924; Stone, 1928). According

to Wyer (1924), the Commonwealth contained 118 glass plants and 25 glass-sand quarries in 1920. Recent production of industrial sands, exclusive of construction sand, averages about 1 million tons annually with an average per ton value of about $14 (Kebblish, 1982). Typical chemical compositions for silica used in the manufacturing of white glass are SiO_2, > 99 percent; Al_2O_3, ~ 0.08 percent; Fe_2O_3, < 0.03 percent; and Cr_2O_3, < 0.0003 percent (Mills, 1985). By comparison, lasca and "Steuben® crystal" products generally require a raw-silica source having impurities limited to a few to a few tens of parts per million (unpublished information).

According to the United States Bureau of Mines (USBM), the nation did not produce any natural quartz suitable for direct electronic or optical applications in 1980 (Zlobik, 1981). Minor amounts of lower grades of natural quartz crystals have been produced in Arkansas and Oklahoma, while California, Idaho, and Virginia have had even more sporadic production. About 90 percent of the lasca consumed in the United States comes from Brazil in the form of quartz crystals. Brazil recently announced that in addition to supplying most of the world demand for lasca, it has purchased a cultured-quartz-growing process which is in production. Furthermore, Brazil has also developed its own technology for growing synthetic quartz crystals (Engineering and Mining Journal, 1981). An official of the state-owned Technology Center Foundation of Minas Gerais, which developed this process, has stated that the cultured quartz can be sold for a minimum of $91 per pound, more than double the average value of U.S.-produced cultured quartz crystals (Engineering and Mining Journal, 1981; Zlobik, 1981). This study was undertaken, in part, to help develop a domestic supply of a critical mineral commodity.

An incentive appears to exist to beneficiate some of the purer silica deposits in the Commonwealth. Anticipated growth in the silicon industry, coupled with increases in lasca prices and demand, could stimulate this high-value, low-tonnage specialty market. Lasca had an average price of $0.60 per pound in 1980 and experienced a 20 percent increase in demand (USBM, 1980). High-purity quartzite from the United States has been successfully used to produce cultured quartz (Hale, 1975). Oscillator, filter, resonator, and transducer plates are the primary uses of both natural and cultured quartz crystal (Zlobik, 1981). Consumption of lasca in the United States in 1980 was 513 tons, valued at an average of $1200 per ton (USBM, 1980). Pennsylvania is located close to over 75 percent of the cultured-quartz-growing facilities in the United States.

SCOPE

Potential high-purity silica sources from nine Paleozoic formations and six quartz veins were sampled, chemically analyzed, and described from 30 locations representing 14 counties in central and eastern Pennsylvania. Percentages of Al_2O_3 and Fe_2O_3 are reported for 67 composite samples, including 37 beneficiated splits. Beneficiation included acid leaching and electromagnetic separation.

Sandstones and quartzites from the Cambrian, Silurian, Devonian, and Pennsylvanian Systems constitute the majority of samples collected, and most were acquired in the fall of 1981. No significant quartz-crystal localities were anticipated or found.

Most laboratory preparation and beneficiation was accomplished in 1982. Several batches of preliminary semiquantitative chemical analyses were received throughout 1983. Quantitative analyses for Al and Fe were received in late 1983. Compilation and interpretations of data were accomplished throughout this period.

LOCATION

Sampling of sedimentary formations was generally confined to the eastern half of Pennsylvania (Figure 1). Vein quartz was examined in the south-central and southeastern part of the state. Silica was studied in most physiographic provinces of central and eastern Pennsylvania. Counties from which samples were collected and chemically analyzed are Adams, Bedford, Berks, Bradford, Chester, Columbia, Cumberland, Franklin, Huntingdon, Lancaster, Monroe, Schuylkill, Tioga, and York. Portions of 7-1/2-minute topographic quadrangles showing the location of each analyzed sample are included in Figures 12 through 33 in the appendix. Table 18, also in the appendix, is a list of the analyzed samples by county.

ACKNOWLEDGEMENTS

In 1981, Robert C. Smith, II, of the Pennsylvania Geological Survey, proposed this study and since has made many valuable contributions to its progress. In addition to reviewing the manuscript, he found one of the best sedimentary Silurian exposures, assisted with some of the field work, con-

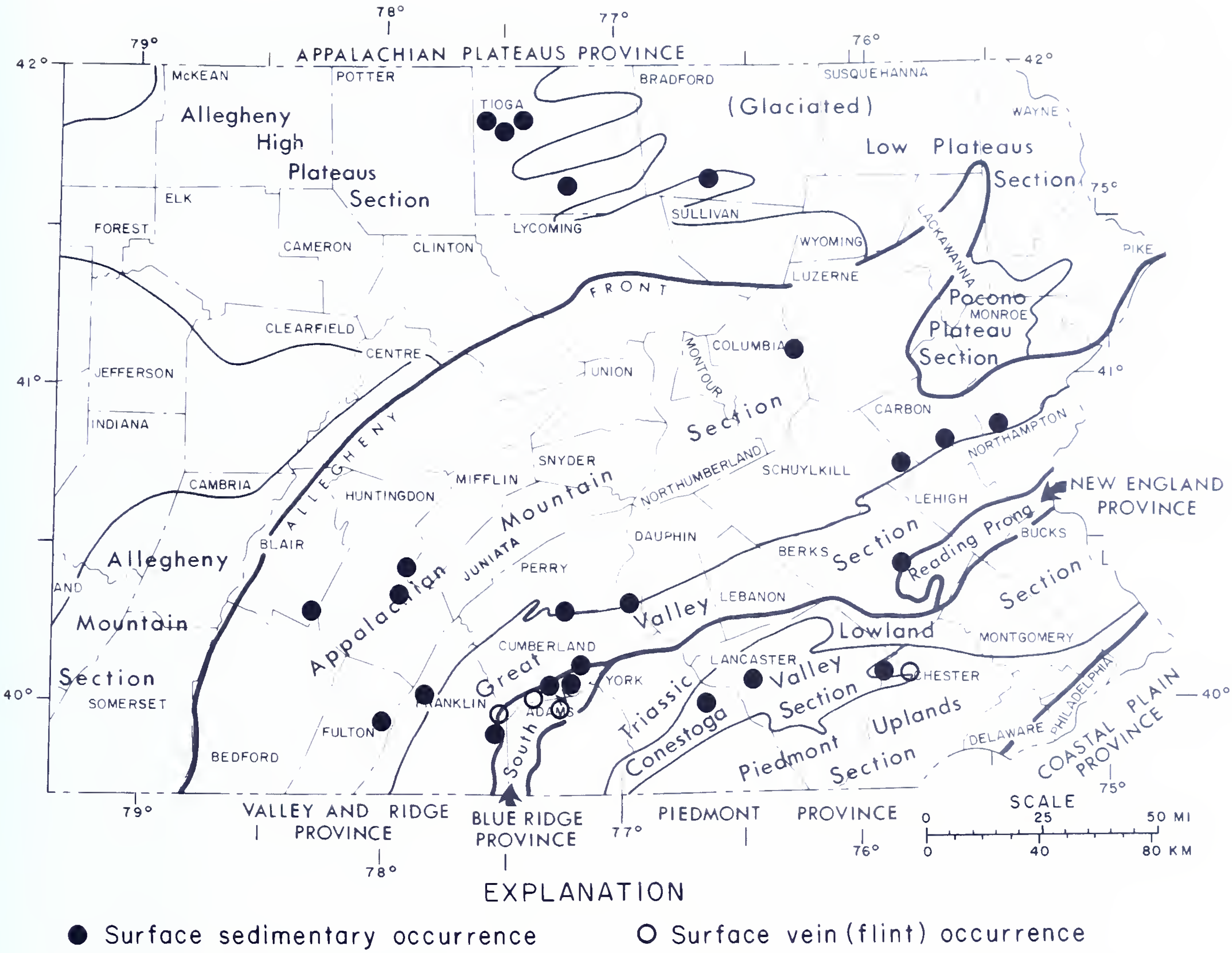

Figure 1. Index map of silica deposits investigated. Not all locations shown yielded samples that were chemically analyzed.

ceived and performed much of the beneficiation work, and was a patient as well as an enthusiastic supporter of the project. John H. Barnes, of the Pennsylvania Geological Survey, performed some preliminary chemical analyses and enhanced the clarity of this report. Leslie T. Chubb, laboratory technician, also of the Survey, assisted with the sample preparation and hand ground all beneficiated samples. Arthur A. Socolow, State Geologist, supported the project and reviewed the manuscript.

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SILICA MINERALOGY

Silica occurs naturally in a number of different forms. The most common is the polymorph called alpha quartz, or low quartz, which makes up about 12 percent of the earth's crust. Alpha quartz is stable below 573°C and is the commercially important form of raw silica. Alpha quartz is the only crystalline form of silica known to occur in Pennsylvania. Frondel (1962) described the thermal stability range of the silica polymorphs in detail.

Alpha quartz has a specific gravity of 2.65 and is optically uniaxial with a mean refractive index of 1.55 (Hurlbut, 1971). Quartz has long been known to have strongly piezoelectric and pyroelectric properties. Diagnostic features include a Mohs' hardness of 7, conchoidal fracture, vitreous luster, and common prismatic crystal form.

STRATIGRAPHIC FRAMEWORK OF SAMPLED INTERVALS

INTRODUCTION

Twenty-four silica occurrences and prospects in Paleozoic formations, as well as six Precambrian or younger quartz veins, were sampled throughout the eastern half of the Commonwealth. Initial sites of investigation were selected from published records and conversations with personnel of the Pennsylvania Geological Survey. Sample sites were selected by field evaluation of the purity and, to a lesser degree, the potential minability of the various occurrences. The best clastic sequences should be derived from a tectonically stable area and be related to beach and/or dune lithofacies. Most sampled intervals, including the vein quartz, have been mined at some time for various industrial products. The analyzed samples are listed by formation in Table 19 (appendix).

PRECAMBRIAN(?)

Quartz Veins

Hydrothermal quartz veins occurring in a Precambrian volcanic sequence of the South Mountain section of the Blue Ridge physiographic province were examined. Freedman (1967) noted and mapped some quartz veins or lenses occurring in Precambrian aporhyolite, aporhyolite porphyry, lavender aporhyolite, and Lower Cambrian muscovitic quartzite of the Loudoun Formation. Similar quartz veins were observed in Precambrian host rocks mapped as blue metarhyolite and greenish phyllite by Fauth (1968).

Individual quartz veins range in width from a few inches to about 65 feet (20 m) and in length from a few tens of feet to about 2 miles (3 km). The Catoctin Formation (Fauth, 1968, 1978), a sequence of volcanic rocks in which most of the significant vein quartz is found, is late Precambrian (Proterozoic Z) in age, ranging between 850 and 600 million years old, depending on dating methods and interpretations (Rankin and others, 1969; Conley, 1978). How much younger the quartz veins are than the host rock is open to speculation. Freedman (1967) reported a quartz vein in the Lower Cambrian quartzitic Loudoun Formation and Stone (1939) reported a quartz vein in the Chickies Formation of Chester County, suggesting a Cambrian or post-Cambrian age for some. Quartz veins formed in the Lower Cambrian quartzite sequences have similar regional settings to the commercial quartz-crystal mineralization exploited in Brazil (see Bates, 1960, p. 273–274).

Bascom and Stose (1938) mentioned some abandoned quartz veins worked for flint and glass in the Devault, Pikeland, Lionville, and Brandywine Manor areas of southeastern Pennsylvania. Bascom and Stose (1932) reported that quartzose pegmatites southeast of Oxford, Pennsylvania, were once mined for quartz used in the manufacturing of chinaware and pottery. Stone (1939) reported occurrences of quartz veins, some up to 50 feet

(15 m) wide, in the South Mountain area near Pine Grove Furnace, Wenksville, Buchanan Valley, and Caledonia, as well as in York County near Woodbine.

CAMBRIAN

The Cambrian rocks investigated consist almost entirely of sedimentary rocks, mostly quartzites, located in the southeastern part of the Commonwealth. Some previously published chemical characteristics of Cambrian sediments are listed in Tables 1 and 2.

Hardyston Formation

The Hardyston Formation occurs in the Reading Prong section of the New England physiographic province. It generally is characterized as light-colored, massive-bedded, fine- to medium-grained quartzite which has a quartz-pebble conglomerate occurring at the base. Estimates of the total thicknesses in the Reading area are on the order of 600 feet (180 m) (Geyer and others, 1963; MacLachlan, 1979). The North American Refractory Brick Company once quarried refractory silica from this formation near Newmanstown in Lebanon County. Many of the abandoned quartzite pits in the Reading area once supplied silica to the steel industry.

Aaron (1969) reported that the lower part of the formation was predominantly alluvial and the upper part shallow marine, representing an overall transgressive event. The upper, usually covered portion was not seen at the sites investigated.

Chickies Formation

The Chickies Formation is restricted to the Conestoga Valley section and the Piedmont Uplands section of the Piedmont physiographic province in Pennsylvania. It generally contains a thin dark slate at the top and a conglomerate at the base. It is composed of a light-colored quartzite and quartz schist. The thickness of this formation is reported to vary from about 550 feet (170 m) to 900 feet (270 m) in Chester, Lancaster, and York Counties (Jonas and Stose, 1926, 1930; Bascom and Stose, 1932; Stose and Jonas, 1939). Goodwin and Anderson (1974) interpreted the environment of deposition as a Cambrian tidal sand body occurring as a mosaic of subtidal channels, intertidal flats, and tidal-flat ponds, which may account for its chemical variability.

Harpers Formation

The more quartzose lithofacies of the Harpers Formation occurs in the South Mountain section of the Blue Ridge physiographic province. It is a dark phyllite and schist containing quartzite layers, including the Montalto Member of the South Mountain area. This member consists of a foliated quartzite, vitreous quartzite, blue quartzite, and

Table 1. *Published Chemical Analyses of Cambrian Sedimentary Rocks*[1]

Sample number	SiO_2	Al_2O_3	Fe_2O_3	CaO	Total percent	Description and comments
56	97.92	0.80	0.85	0.09	99.66	Hardyston Formation(?), Lebanon County, gap in South Mountain near Newmanstown.
63	97.60	.88	1.13	.10	99.71	Hardyston Formation, Berks County, from Bertolet and Hunter property at Temple, near Reading.
64	97.20	1.08	1.35	—	99.63	Hardyston Formation, Berks County, Sugar Head Hill, 1/2 mile (0.8 km) from Shillington, near Reading. Small hill on which the High Point Stone quarry is located.
58	97.80	.92	.86	.10	99.68	Chickies Formation, Lancaster County, Harbison-Walker Refractories Company quarry at Narvon.
60	97.51	.99	1.08	.11	99.69	Chickies Formation, Lancaster County, on Susquehanna River about 1-1/4 miles (2 km) above Columbia.
1	97.10	1.39	1.25	.18	99.92	Chickies Formation, Lancaster County, Chickies Rock.

[1]For samples 56, 58, 60, 63, and 64, data were modified from Moore and Taylor (1924); for sample 1, data were modified from Jonas and Stose (1930).

Table 2. *Summary of Characteristics of Cambrian Clastic Rocks, South Mountain Area of Adams, Cumberland, and Franklin Counties*
(Data from Fauth, 1968)

Formation or member	Quartz (Percent)[1]	Feldspar (Percent)[1]	Feldspar (Type)[2]	Sorting	Roundness	Nonopaque heavy minerals[2]
Antietam Formation	Range 78–99 Mean 91	Range 0–3 Mean <1	Plagioclase Microcline	Good	Subrounded to rounded	TOURMALINE, ZIRCON, rutile
Harpers Formation (upper)	Range 60–71 Mean 64	Range 3–6 Mean 4	MICROCLINE Plagioclase	Moderate	Subrounded	TOURMALINE, zircon
Montalto Member (upper)	Range 82–98 Mean 89	Range 0–1 Mean <<1	MICROCLINE Plagioclase	Good	Subrounded	Tourmaline, zircon
Montalto Member (lower)	Range 82–97 Mean 89	Range 0–2 Mean 1	MICROCLINE Plagioclase	Good	Subrounded	Tourmaline, zircon
Weverton Formation (upper members)	Range 65–98 Mean 82	Range 0–4 Mean 2	MICROCLINE Plagioclase	Moderate to good	Subrounded to subangular	TOURMALINE, EPIDOTE, zircon
Weverton Formation (lower members)	Range 56–88 Mean 71	Range 0–3 Mean <1	PLAGIOCLASE Microcline	Moderate	Subrounded to subangular	TOURMALINE, EPIDOTE, sphene, zircon
Loudoun Formation (conglomerate)	Range 58–69 Mean 66	Range 0–4 Mean 2	PLAGIOCLASE Microcline	Fair	Subrounded to subangular	SPHENE, EPIDOTE, zircon, tourmaline

[1]Percentage estimates are based on point-count data and visual comparison charts.
[2]Most abundant minerals are capitalized.

greenish quartzite and is about 1,500 feet (460 m) thick as mapped in this area by Freedman (1967). Generally, this sequence of clastics is correlated with the Chilhowee Group and represents a total thickness of about 2,500 to 3,100 feet (750 to 950 m) according to Fauth (1968). He also reported a white to gray protoquartzite[1] unit 700 to 800 feet (210 to 240 m) thick occurring in the upper part of the Montalto Member.

Antietam Formation

The purer sequences of the Antietam Formation are restricted to the South Mountain section of the Blue Ridge physiographic province and the Conestoga Valley section of the Piedmont physiographic province. The Antietam is generally described as a gray- to buff-weathering quartzite, locally becoming a quartz schist. Weathering has locally made this quartzite quite friable. It is reported to be about 700 to 900 feet (210 to 270 m) thick and rather pure in the South Mountain area, but is less pure and apparently thins to the east in Lancaster County to about 150 feet (45 m) (Fauth, 1968; Jonas and Stose, 1926). Kauffman and Frey (1979) suggested that the Antietam Formation represents exhumed barrier-island sedimentary facies. Wilshusen and Sevon (1981) interpreted megaripples in Franklin County as having formed nearshore by wave-generated ripples during a shallowing-water episode.

SILURIAN

Tuscarora Formation

The Silurian Tuscarora Formation has played a historic role in the silica refractory (ganister) industry of Pennsylvania. The formation consists of light-colored quartzite and sandstone (orthoquartzite[2]) with minor interbedded shale. Locally the lower part is conglomeratic. It is of geomorphic significance in forming prominent resistant ridges in the Appalachian Mountain section of the Valley and Ridge physiographic province. The flanks of these ridges locally contain abundant rock floes (talus, scree, or colluvium of loose ganister) and boulder fields.

The formation varies in total thickness, ranging from a maximum of about 500 feet (150 m) near Lamar, Clinton County, Bellefonte, Centre County, and Mount Union and Shy Beaver, Huntingdon County; to about 400 feet (120 m) toward the southwest, in the Bedford area; about 300 feet (90 m) toward the south and southeast, in southern Huntingdon, Franklin, and Dauphin Counties; and about 200 feet (60 m) in the Williamsport area (Moore and Taylor, 1924).

In recent investigations Cotter (1982, 1983) identified a "basal horizontally laminated lithofacies," which is a quartz arenite (orthoquartzite) containing more than 98 percent quartz and rare chert and lithic fragments. This basal unit has the highest silica content known in the Tuscarora sequence. Additional features of this unit reported by Cotter include symmetrical wave-generated ripples, fine- to medium-grained monocrystalline quartz, supermature rounded and well-sorted grains, no shale as clasts or interbeds, and common horizontal laminations with some concentrations of heavy minerals along laminae. The burrows of *Skolithos* and *Monocraterion* are common, but no *Arthrophycus* burrows are found. This lithofacies has been interpreted by Cotter to represent a foreshore and shoreface beach environment of deposition. Figure 2 shows the thickness of this lithofacies based on Cotter's published data and observations made in this investigation. At some of the locations shown, such as Susquehanna Gap and Roxbury, the unit, although still a basal quartz arenite, is highly stained with iron. Nevertheless, the available thickness data suggest that portions of Bedford, Blair, Cumberland, Franklin, Fulton, Huntingdon, and Perry Counties contain minable thicknesses (50 feet (15 m) or greater).

Table 3 illustrates the range in oxide values in previously published chemical analyses of this formation from various localities and lithofacies within the Commonwealth. For specific sample locations and descriptions, see Moore and Taylor (1924, p. 29–32).

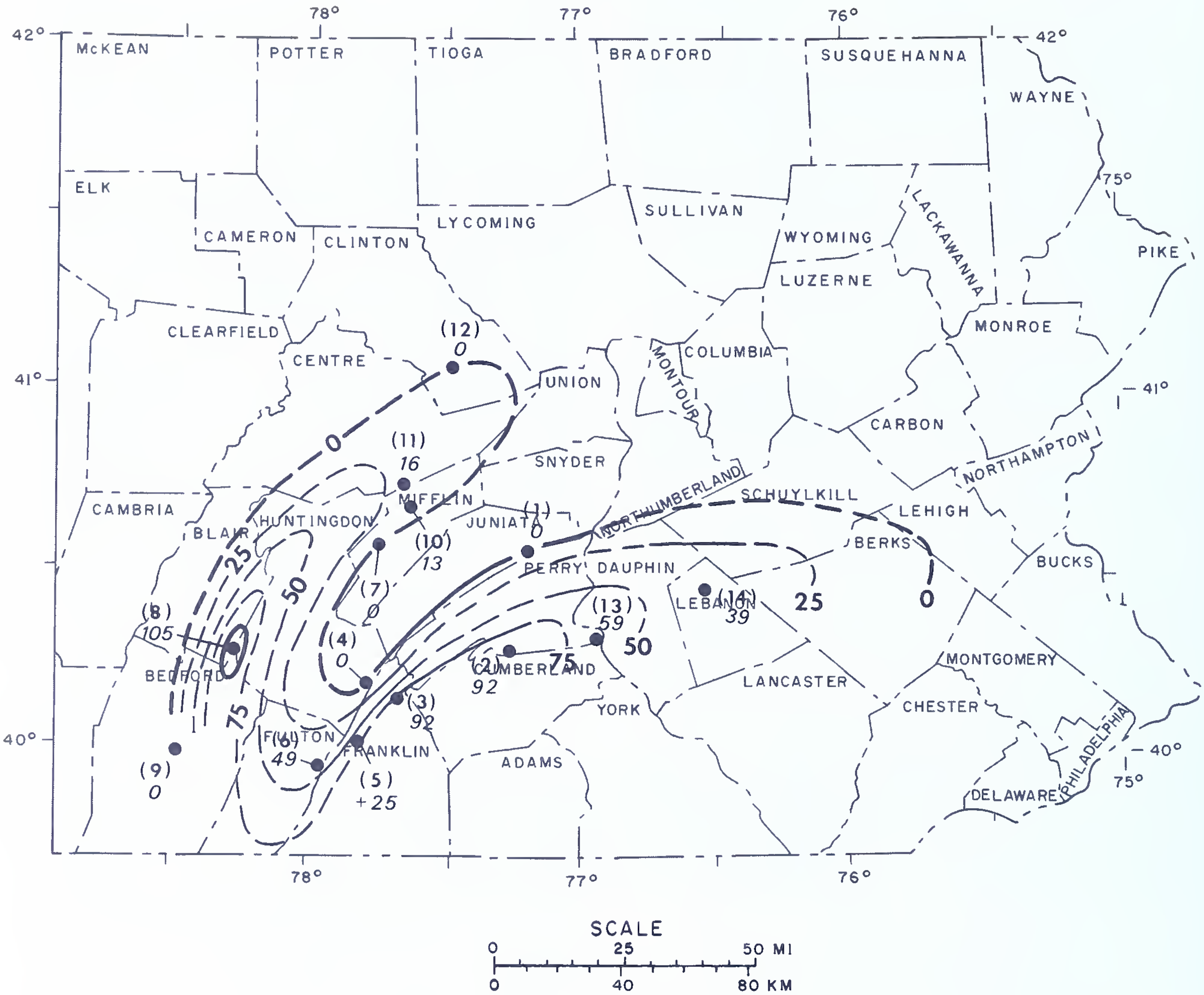
DEVONIAN

Old Port Formation ("Oriskany")

The Ridgeley Member of the Old Port Formation (Conlin and Hoskins, 1962) crops out in the southern part of the Pennsylvania portion of the Appalachian Mountain section of the Valley and Ridge physiographic province. Commonly, it is known as the "Oriskany" glass sand and has been a major source of white and amber silica for the glass industry for many years. This member consists of a light-colored fine- to very coarse grained sandstone averaging about 120 feet (35 m) in

[1]A lithic sandstone containing between 75 and 95 percent well-sorted quartz.

[2]A sandstone containing more than 90 to 95 percent well-sorted, well-rounded quartz and lacking a fine-grained matrix.



Sample number	Location	Thickness (feet)	Sample number	Location	Thickness (feet)
(1)	Millerstown	0	(8)	Martinsburg	105
(2)	Wagganers Gap	92	(9)	Bedford	0
(3)	Roxbury	92	(10)	Kishacoquillas Gap	13
(4)	Neelytan	0	(11)	Seven Mountains	16
(5)	Weaver Gap	+25	(12)	Mill Hall	0
(6)	Firetawer	49	(13)	Susquehanna Gap	59
(7)	Jacks Mountain	0	(14)	Swatara Gap	39

Figure 2. Generalized isopach map of Cotter's (1982, 1983) "basal horizontally laminated lithofacies" of the lower portion of the Silurian Tuscarora Formation. Based on outcrop data from Cotter and this investigation. Contour interval 25 feet.

thickness in Huntingdon and Mifflin Counties, where it is purest and is being exploited (Fettke, 1919). Chemical analyses listed in Table 4 for the Ridgeley Member are from once-active quarries in east-central Huntingdon County and southwestern Mifflin County that were sampled and analyzed by C. R. Fettke (1919). Grain-size analyses by Fettke reveal that most sand (about 95 percent) is between minus 28 mesh and plus 65 mesh. This member characteristically forms resistant ridges on the flanks of anticlinal and synclinal structures.

Figure 3 illustrates the thickness variation of the "Oriskany" in central Pennsylvania. The thickest developed sequence occurs on Warrior Ridge in

Table 3. ***Published Chemical Analyses of Tuscarora Formation***

(Selected data from Moore and Taylor, 1924)

Sample number	SiO_2	Al_2O_3	Fe_2O_3	CaO	Total percent	Description and comments
13	97.98	0.90	0.70	0.10	99.68	Juniata County, Haws Refractories Company quarry at Hawstone near Lewistown, floe.[1]
14	98.02	.87	.79	.11	99.79	Huntingdon County, Harbison-Walker Refractories Company quarry at Mount Union, floe.
15	98.02	.93	.73	.12	99.80	Huntingdon County, Mount Union Refractories Company quarry, Three Springs. High-grade rock, 25 feet (8 m) thick.
16	97.82	.90	.83	.10	99.65	Huntingdon County, General Refractories Company quarry, Neelytown, ledge.
25	98.06	.81	.70	.09	99.66	Blair County, east side of Altoona Gap, Brush Mountain, floe.
34	98.10	.79	.81	.11	99.81	Blair County, north slope of Lock Mountain between Point View and Sissler, floe.
37	98.06	.84	.76	.12	99.78	Blair County, Harbison-Walker Refractories Company stripping near Goodman Station, large floe.
38	97.70	.82	1.01	.12	99.65	Bedford County, Tate's quarry at Cliffs, Evitts Mountain, ledge.
39	98.11	.85	.80	.09	99.85	Bedford County, E. R. Baldridge Company quarry at Wolfsburg, ledge, part high-grade.
44	98.10	.80	.80	.10	99.80	Bedford County, quarry on Mount Dallas, floe.
50	98.04	.86	.83	.10	99.83	Franklin County, south slope of Franklin Furnace Gap, floe.
61	98.10	.78	.79	.09	99.76	Bedford County, gap in Tussey Mountain at Loysburg, floe.
62	98.10	.80	.67	.11	99.68	Huntingdon County, south side of Tussey Mountain south of Pennsylvania Furnace.

[1]The term "floe" pertains to talus, scree, and colluvium of ganister (quartzite used for the manufacture of silica refractories).

Table 4. ***Published Chemical Analyses of the Ridgeley Member of the Old Port Formation ("Oriskany") in Huntingdon County***

(Data from Fettke (1919) except where indicated)

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	H_2O	TiO_2	Total percent	Description and comments
99.39	0.30	0.12	None	0.29	0.17	0.03	100.30	Westbook quarry, Huntingdon County, bluish-gray quartzite.
98.75	.52	.03	None	.28	.17	.03	99.78	Same as above. Sand derived from quartzite by weathering.
[1]99.36	.17	.06	None	.28	.13	.02	100.02	Keystone Works, Huntingdon County, analyses of No. 1 sand.
[1]99.70	.24	.026	Trace	Trace	—	—	99.966	do.
99.76	.14	.07	None	.28	.09	.02	100.36	Keystone Works, Huntingdon County, South quarry, analysis of glass sand.
[1]99.72	.25	.014	Trace	Trace	—	—	99.984	Columbia Works, Huntingdon County, analysis of sand.
[1]99.885	.022	.047	Trace	.020	—	—	99.974	Pittsburg White Sand Company, Huntingdon County, analysis of No. 1 sand from plant.
[1]99.85	.14	.012	—	Trace	—	—	100.002	Juniata White Sand Company, Huntingdon County, analysis of No. 1 sand from plant.
[2]98.96	.33	.50	—	.05	—	—	99.84	Pennsylvania Glass Sand Company, Huntingdon County, quarry at Mapleton.

[1]Samples may be beneficiated(?), which generally consists of commercial washing.
[2]Analysis and data from Moore and Taylor (1924), sample 45.

Bedford County, where the outcrop was measured by plane-table methods (Wallace de Witt, personal communication, 1983). Some local basal limy units are represented in this illustration. Major historic glass-sand production came from southwestern Mifflin County and east-central Huntingdon County. The available thickness data suggest that sequences greater than 100 feet (30 m) thick exist in Bedford, Blair, Fulton, Huntingdon, and Mifflin Counties.

It has been suggested that this member represents recycled older sedimentary rocks such as Silurian and Cambrian quartzites (Cleaves, 1937; Fettke, 1919; Inners, 1975; Stow, 1938). Stow

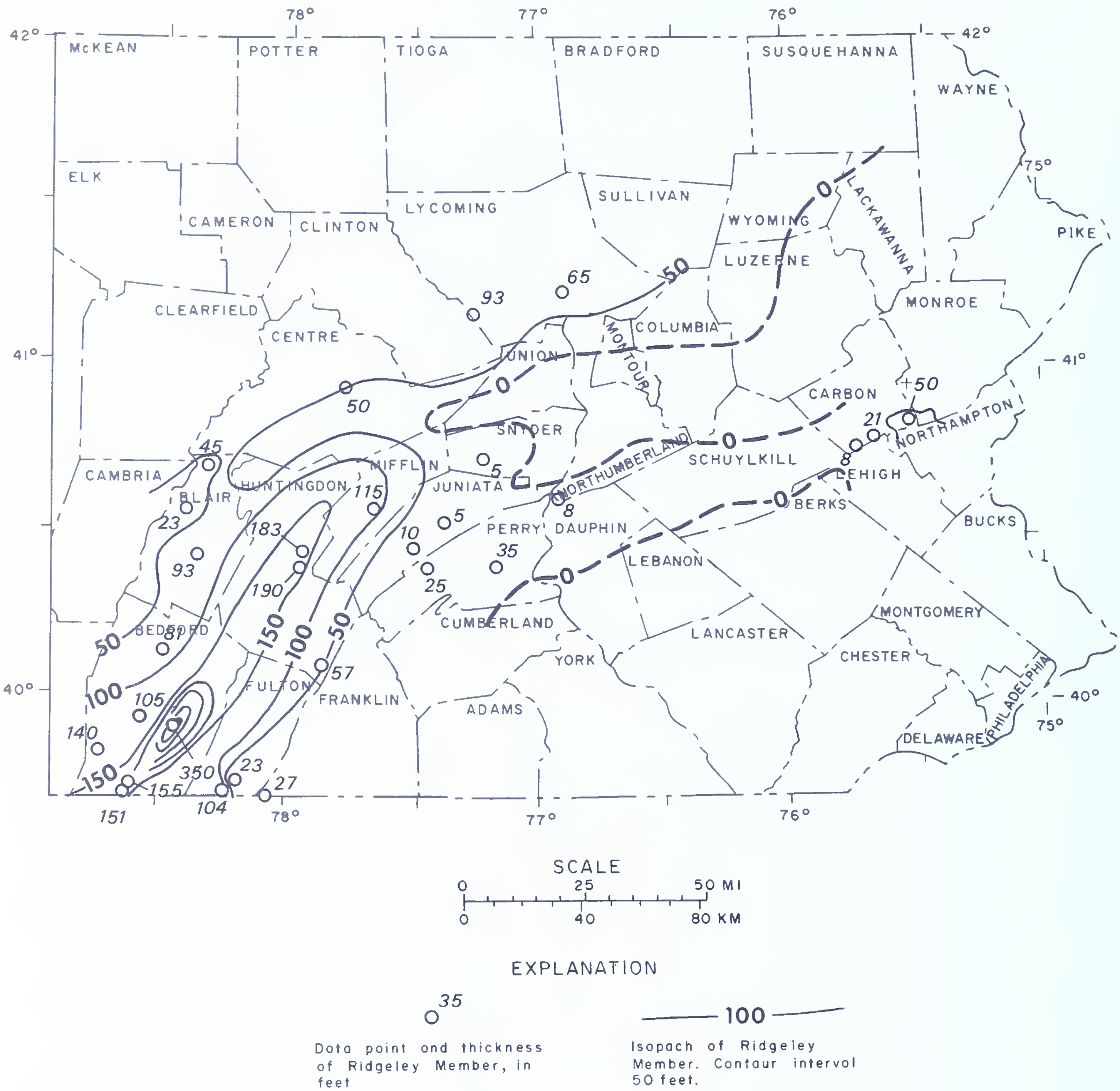


Figure 3. Generalized isopach map of the Devonian Ridgeley Member of the Old Port Formation ("Oriskany") in eastern Pennsylvania. Data compiled from Abel and Heyman (1981), Conlin and Hoskins (1962), Dennison and others (1979), de Witt (1974), Dyson (1963), Epstein and others (1974), Faill and others (in press), Fettke (1919), Inners (1975), Miller (1961), Wells and Bucek (1980), and Willard and others (1939).

(1938) concluded that the heavy-mineral suites of tourmaline, zircon, rutile, and leucoxene indicate a sedimentary provenance. Ridgeley environments of deposition in Pennsylvania include a deep subtidal environment, represented by cherty limestone and limy chert, shallow subtidal deposition, represented by quartz sandstone, and shallow subtidal mixed with intertidal deposition, represented by conglomeratic sandstone (Inners, 1975). Inners also postulated that the major source area of the sand was southeastern Pennsylvania.

Palmerton Formation

The Palmerton Formation is restricted to the southeastern part of the Pennsylvania portion of the Appalachian Mountain section of the Valley

and Ridge physiographic province. It is a massive white siliceous sandstone occurring in eastern Pennsylvania. It, too, historically has been a reliable source of refractory and construction sand. Bedrock occurrences range in induration from friable to quartzitic and are complexly folded into a series of overturned anticlines and synclines (Figure 4). Thicknesses in Schuylkill, Carbon, and Monroe Counties average about 70 feet (20 m) and suggest that minable thicknesses are present (Fig-

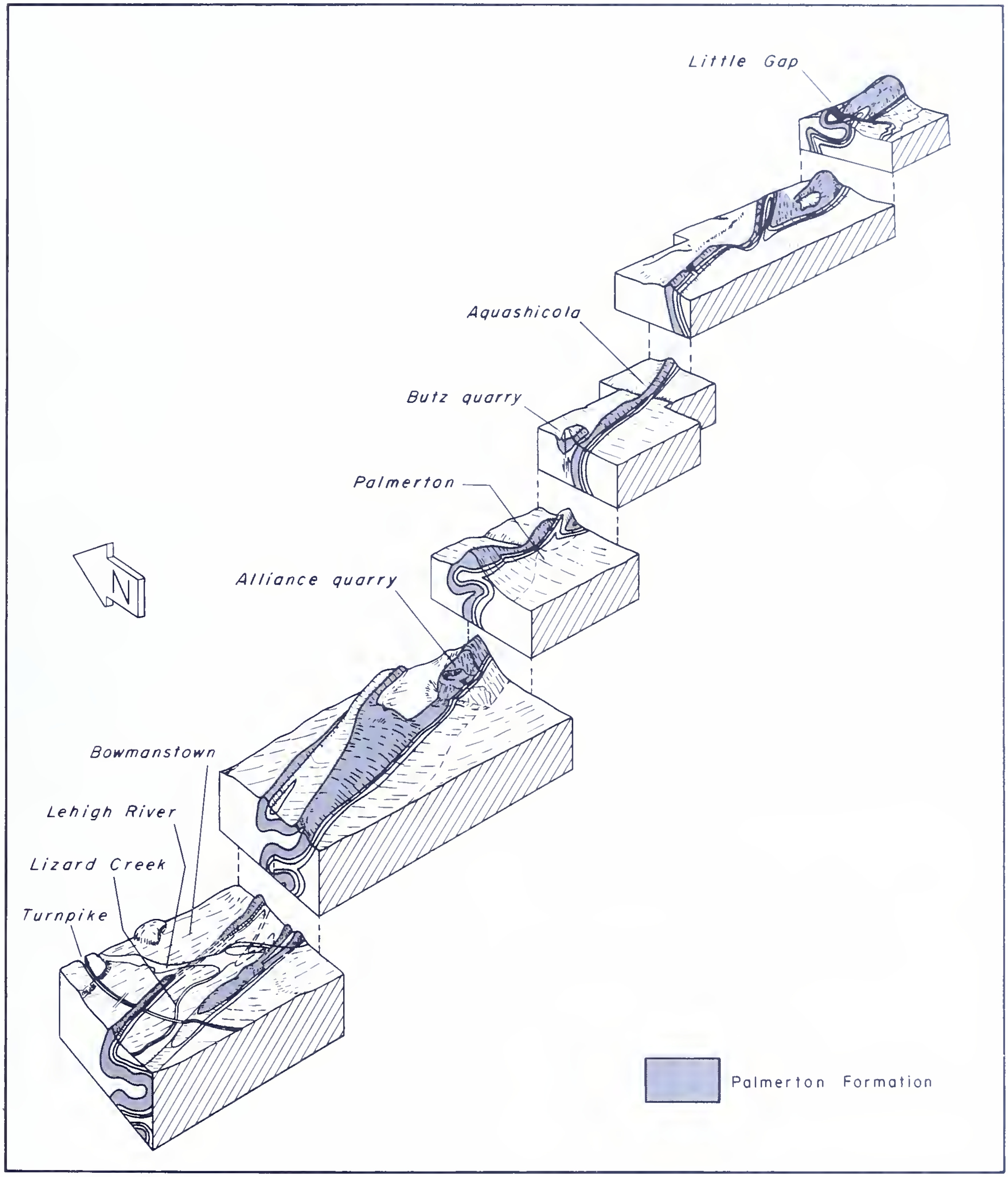


Figure 4. Block diagram showing the structural complexity of the Palmerton Formation between the Lehigh River and Little Gap. Modified by Sevon (1970) from an unpublished original by J. F. Wietrzychowski.

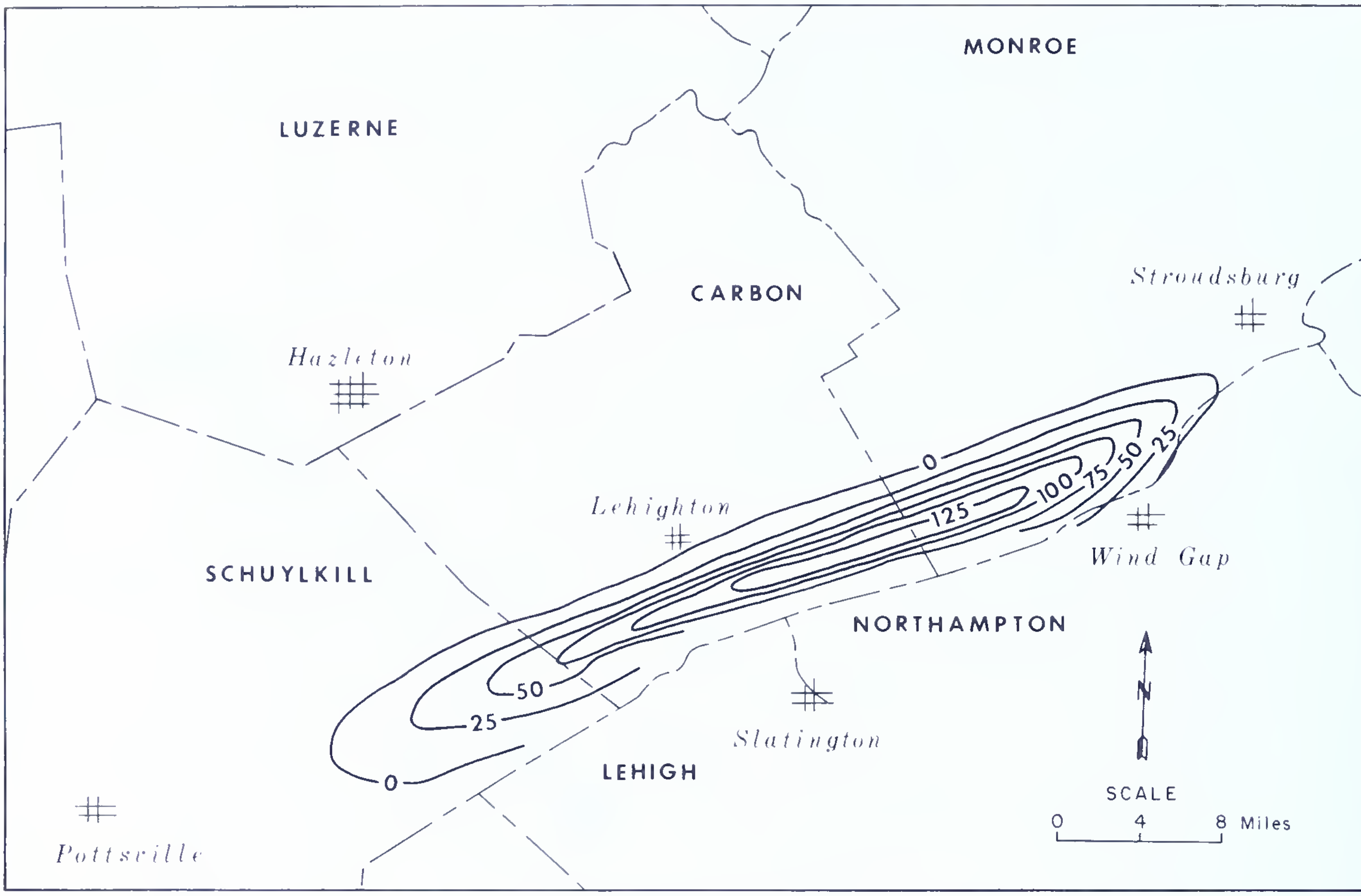


Figure 5. Isopach map of the Palmerton Formation (from Inners, 1975). Contour interval 25 feet.

ure 5). Clay and hematite are locally the most common constituents other than quartz. Grain size analyses by Inners (1975) and Sevon (1970) reveal that most quartz grains are between 1 and 2 mm in diameter. Some chemical analyses from the now-abandoned North American Refractories Company operation at Little Gap are listed in Table 5.

Table 5. *Published Chemical Analyses of the Palmerton Formation*

(Analyses of beneficiated samples by North American Refractories Company at Little Gap; data from Sevon, 1970).

	A (percent)	B (percent)
SiO_2	98.75	98.64
Al_2O_3	.12	.23
TiO_2	.02	.02
Fe_2O_3	.73	.79
CaO	Trace	Trace
MgO	Trace	Trace
Na_2O	.02	.02
K_2O	.02	.01
Ignition loss	.34	.29

Inners (1975) interpreted that the sandstone was deposited as a marine(?) bar, albeit in a high-energy environment. Epstein and others (1974) suggested that this sand body may have accumulated in a nearshore or foreshore environment in response to temporary shallowing water.

MISSISSIPPIAN

Pocono Formation

The middle Mississippian Pocono Formation was investigated in Columbia and Luzerne Counties and was brought to the author's attention by J. D. Inners (personal communication, 1982). Small outcrops were examined on the south limb of the Lackawanna syncline forming Huntington Knob and Lee Mountain in the Appalachian Mountain section of the Valley and Ridge physiographic province. The Pocono Formation can generally be characterized as light-colored quartzitic sandstone and conglomerate. Carbonized plant fragments are common locally. Most specimens contain some staining that appears hematitic. Inners (1978) estimated the thicknesses to vary between about 600 and 650 feet (180 and 200 m). He

also interpreted most of these sediments to have been deposited as braided-river sequences, which included localized freshwater swamp environments producing thin coaly shales.

PENNSYLVANIAN

Pottsville Group

The lower Pottsville Group of sediments has been used in the past as a source of raw material for amber glass. Published chemical analyses are presented in Table 6. Locally some of these exploited units have been known as the Sharon and Olean Conglomerates in western Pennsylvania. In northeastern Pennsylvania, eroded remnants of these rocks are found in synclinal axes of isolated outliers both in the Allegheny High Plateaus section and the (Glaciated) Low Plateaus section of the Appalachian Plateaus physiographic province. The lower 50 to 100 feet (15 to 30 m) of the Pottsville (Lower Pennsylvanian) is generally characterized as a prominent light-colored sandstone and conglomerate which disconformably overlies various Mississippian clastics.

Stratigraphic relationships of this basal sequence of clastics are complicated by sediment input from both a northern and southeastern source (Berg and others, 1981). The northern source was derived from the reworking of cratonic sediments in Canada and New York (Fuller, 1955). The southern source is believed to be orogenic highlands composed generally of metamorphic and sedimentary rocks (Meckel, 1967). Preliminary interpretations of depositional environments for north-central Pennsylvania suggest anastomosing streams on an alluvial plain (Berg and others, 1981). Obviously, the coarse grain size indicates periods of high energy, and large tonnages of consistent quality may be difficult to block out.

The Connoquenessing sandstones and the Homewood Sandstone, of the Middle and Lower Pennsylvanian Pottsville Group, also have contributed to the glass industry in the western part of the state, but were not studied in this investigation. They locally consist of sublitharenites (protoquartzites; see page 7, footnote) and quartzarenites (orthoquartzites; see page 7, footnote). Ninety percent of the Connoquenessing and Homewood quartz grains generally are sized between 28-mesh and 150-mesh screens (Fettke, 1919). For details of the Carboniferous stratigraphy in Pennsylvania and New York, see Edmunds and others (1979).

SAMPLE PREPARATION AND ANALYSES

Descriptions of the samples analyzed, including location, petrography, sample type, potential uses, and comments, are included in Tables 16 and 17. Samples from each locality selected for chemical analysis were analyzed in two splits: "as-collected" and "beneficiated" (identified by a "B" following the sample number). Selected samples were further beneficiated and are referred to as "superbeneficiated" (identified by a "BB" following the sample number). Face samples refer to samples obtained by taking composite chips from the exposed walls of a quarry or pit.

SAMPLE PREPARATION

Due to the high purity levels anticipated (~10 ppm Al_2O_3 and Fe_2O_3) for some samples, special care was taken in preparing the samples. Every effort was made during sample collection to obtain representative samples that were clean and fresh. All samples were weighed and washed in the lab-

Table 6. *Published Chemical Analyses of Lower Pottsville Group Sandstones*

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	H_2O	TiO_2	Total percent	Description and comments
[1]98.35	1.14	0.06	Trace	0.11	0.21	0.14	100.01	Venango County, Pittsburgh Plate Glass Company at Kennerdell, selected pure quartz sandstone from quarry.
[1]96.08	2.35	.37	.08	.18	.67	.15	99.88	Elk County, Fox Silica Sand Company at Doguscahonda, average sample of unwashed sand.
[2]97.94	.83	.86	—	.09	—	—	99.72	Potter County, Galeton, 50-foot- (15-m-) thick bed.
[3]97.54	.81	.09	.06	1.04	.03	—	99.57	Westmoreland County, sand from the flank of Laurel Ridge near Seward.

[1]Data from Fettke (1919).
[2]Data from Moore and Taylor (1924).
[3]Data from Phalen (1910).

oratory. Most commercial high-purity silica products have, at the minimum, been washed. Therefore, samples that have been washed are reported as "as-collected" in this investigation. Washing consisted of repeated agitation of the sample with tap water in a plastic tub until the water stayed relatively clear. This procedure removed clay from some samples, but was less effective than commercial washing (see samples S-6-81 and S-8-81).

Primary sample reduction was accomplished by step crushing to about minus 1 cm in a Denver Fireclay Company No. 2 jaw crusher. A total of about 450 pounds (200 kg) was crushed. The loss in weight of the crusher plates due to wear suggests that about 145 ± 45 ppm of metal was added to a typical sample. This metal consisted mainly of iron and manganese with major to minor chromium (J. H. Barnes, personal communication, 1983). Sample splits of the crushed silica, used for analyses of both as-collected and beneficiated material, were scanned at a distance of not more than about 0.5 inch (1 cm) with a hand-held ceramic magnet in an attempt to remove tramp iron. Because the jaw-crusher plates are only weakly magnetic, this procedure probably did not result in recovery of all of the tramp metal. Linear (high-density) polyethylene sieves were used to separate samples for magnetic beneficiation and help eliminate contamination.

Sample splits of the as-collected samples were pulverized to minus 100 mesh in a BICO-made Braun Direct Drive Pulverizer, JD 32, using Coors ceramic plates. The sample splits to be beneficiated were also pulverized, but only so that a majority of the sample passed through the 40-mesh sieve and was retained on the 60-mesh sieve, to allow for ease of later magnetic beneficiation. Approximately 33 pounds (15 kg) of silica was pulverized. Measurement of weight loss of the ceramic plates suggests that about $1{,}900 \pm 700$ ppm of ceramic material (mostly Al_2O_3) was added to a typical sample. Beneficiated samples were hand ground to minus 100 mesh after beneficiation, using an agate mortar and pestle. Estimates of the agate purity and wear suggest that this is a negligible source of contamination.

SAMPLE BENEFICIATION

Preliminary beneficiation for one split of each sample consisted of a 100 °C 50 percent H_2SO_4 bath for 6 hours, followed the next day by a 55 °C 50 percent HCl bath for 6 hours. Samples were stirred at half-hour intervals. The H_2SO_4 probably removed some of the Al_2O_3 that was in the form of clay-mica (Grim, 1968). The term "clay-mica" as used in this report refers to various mixtures of light-colored clays and microscopic mica. It includes, but is not restricted to, illite, kaolinite, "sericite," and muscovite. The HCl probably removed some of the oxidized iron, such as common limonitic and hematitic staining. In addition, these acids were chosen because of their commercial availability at reasonable cost and probable recoverability without environmentally or economically unacceptable losses.

Magnetic beneficiation, using a Frantz Isodynamic Magnetic Separator, Model L-1, was standardized for each beneficiated sample. To further reduce the amount of tramp iron that might be in the sample, one pass was made with the separator set at 2-degree side slope, 15-degree front slope, and 1 ampere. This was followed by two passes at 0.5-degree side slope and 1.5 amperes. The choice of these settings was based on preliminary runs of selected samples. At the chosen settings, total loss due to magnetic beneficiation averaged less than 9 percent of the initial sample weight. Details of percentage of loss and mineralogy of the magnetic fractions are reported in Table 7.

Seven of the more promising beneficiated samples were selected for additional magnetic beneficiation and are referred to as superbeneficiated, and designated by "BB" in the sample number. These superbeneficiated samples were prepared from separate splits that were subjected to acid baths as previously described and the removal of tramp iron with one initial pass through the magnetic separator at a 2-degree side slope and 1 ampere. Each sample was then magnetically custom processed with a varying number of passes and side-slope angles. These superbeneficiated samples averaged about 55 percent loss by weight. Details of individual settings, percentage of loss, and mineralogy are reported in Table 7.

Other methods of superbeneficiation were investigated, but these were abandoned because of unlikely commercial feasibility. Mineral preparation studies would be of great value in this regard. Heavy-media separation was not attempted because zircon did not seem to be a problem in the samples studied. Flotation and spiral-gravity methods were not attempted because of their unavailability in the Survey's laboratory, but should be considered. Attempts to improve the magnetic susceptibility of oxidized iron by reduction in graphite crucibles at 1000 °C were unsuccessful. This could mean that the iron in the sample tested was protected as small inclusions. No decrepitation or thermal shock was noted in this sample (S-20-81).

Table 7. *Descriptions of Silica Samples Magnetically Beneficiated, Beneficiation Parameters, and Mineralogy of Magnetic Fractions*

Sample number	Locality name	County	Geologic age Formation	Percentage of loss by weight (magnetic fraction)	Magnetic beneficiation procedure[1]	Mineralogy of magnetic fraction: Major (>10 percent)	Minor (10–1 percent)	Trace (<1 percent)
S-1B-81	Berks Silica Sand quarry	Berks	Cambrian Hardyston	5	2 passes at 0.5° side slope and 1.5A	Milky and/or frosted quartz grains; some clear grains	Dark opaque minute inclusions	Zircon grains and inclusions; white "clay-mica"
S-6B-81	Huss Contracting Company and Refractory Sand Company	Schuylkill	Devonian Palmerton	9	do.	Clear quartz grains; abundant milky and/or frosted grains	—	Vermicular chlorite(?) inclusions; dark opaque inclusions; white "clay-mica"
S-6BB-81	do.	do.	do.	61	3 passes at 0.2° side slope and 1.5A	Increasing amount of milky quartz grains(?)	—	Same as S-6B-81, but contains possible phosphatic fragments(?)
S-8B-81	do.	do.	do.	5	2 passes at 0.5° side slope and 1.5A	Milky and/or frosted quartz grains; clear quartz veins common	Vermicular chlorite(?), inclusions to trace	White "clay-mica"; yellow inclusions (platy titanite?); dark opaque inclusions
S-17B-81	Eastern Industries, Kunkletown	Monroe	do.	7	do.	Milky and/or frosted quartz grains	Some clear quartz grains	Dark minute opaque inclusions; vermicular chlorite(?); white "clay-mica"
S-20B-81	Benders quarry, Mount Holly Springs	Cumberland	Cambrian Antietam	8	do.	do.	—	Dark minute opaque inclusions; schorl tourmaline; zircon inclusions(?)
S-20BB-81	do.	do.	do.	49	3 passes at 0.2° side slope and 1.5A	do.	—	Same as above, but contains less tourmaline and some iron-stained rose and yellow quartz
S-21B-81	Hempt Brothers, Toland	do.	Cambrian Harpers, Montalto Member	14	2 passes at 0.5° side slope and 1.5A	do.	—	Schorl tourmaline grains and inclusions; white "clay-mica" coatings; iron-stained rose quartz, platy mineral (titanite?); zircon inclusions(?)
S-22B-81	do.	do.	do.	13	do.	do.	Schorl tourmaline, inclusions and grains to trace	Iron-stained rose quartz; white "clay-mica"; possible zircon inclusions(?)
S-23B-81	State borrow pit, Pine Grove Furnace	do.	do.	13	do.	Milky and/or frosted quartz grains and clear quartz grains	—	Minute dark opaque inclusions; possible zircon; rare iron-stained rose and yellow quartz grains
S-23BB-81	do.	do.	do.	36	2 passes at 0° side slope and 1.5A	do.	Faint iron-stained quartz (red and yellow)	do.

Table 7. *(Continued)*

Sample number	Locality name	County	Geologic age Formation	Percentage of loss by weight (magnetic fraction)	Magnetic beneficiation procedure[1]	Mineralogy of magnetic fraction: Major (>10 percent)	Minor (10–1 percent)	Trace (<1 percent)
S-26B-81	Abandoned Summit Mining Company pit	Adams	Precambrian(?) Quartz vein	5	2 passes at 0.5° side slope and 1.5A	Milky quartz grains; some clear quartz containing inclusion trains	—	Rare muscovite grain or inclusion; rare dark opaque inclusion
S-27B-81	Abandoned Moses Black quartz vein	do.	do.	5	do.	do.	—	Chlorite/muscovite grains and inclusions; very minute dark opaque inclusions
S-27BB-81	do.	do.	do.	63	3 passes at 0.2° side slope and 1.5A	do.	—	Same as sample S-27B-81, but contains increasingly less chlorite/muscovite
S-28B-81	Abandoned Caledonia North quartz vein	Franklin	do.	7	2 passes at 0.5° side slope and 1.5A	Clear quartz containing some milky inclusion trains	—	Rare, very minute, dark opaque inclusions
S-29B-81	Abandoned Caledonia South quartz veins	do.	do.	1	do.	Milky quartz grains	—	do.
S-30B-81	Dead Woman Hollow quartz vein	Cumberland	do.	2	do.	do.	—	White "clay-mica" grains; rare minute dark opaque inclusions
S-32B-81	Warwick Sand Company	Tioga	Pennsylvanian Lower Pottsville Group	11	do.	Milky and/or frosted quartz grains	White "clay-mica" coatings; muscovite grains to trace	Iron-stained quartz; schorl tourmaline; minute dark opaque inclusions
S-35B-81	High Mountain quarry	do.	do.	6	do.	Milky and/or frosted quartz grains; some clear quartz	Brown (species unknown) and schorl tourmaline; both are rounded and euhedral	Zircon; brookite (possibly altered to anatase); anatase; rare rutile as grains and inclusions; dark inclusions
S-36B-81	do.	do.	do.	5	do.	do.	do.	do.
S-37B-81	Sunfish Pond	Bradford	do.	4	do.	Milky and/or frosted quartz grains	Iron-stained quartz grains (rose and yellow)	Muscovite grains; minute dark opaque inclusions; tourmaline
S-38B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Franklin	Cambrian Antietam	8	do.	do.	—	Iron-stained quartz grains (light rose and yellow); tourmalines; white "clay-mica"; dark inclusions
S-39B-81	do.	do.	do.	5	do.	do.	—	do.
S-41B-82	Lee Mountain	Columbia	Mississippian Pocono, lower half	7	do.	Clear quartz grains; some milky grains and veils	—	Brown tourmaline; "clay-mica" grains; dark opaque inclusions

S-46B-82	Valley Forge Stone	Chester	Cambrian Chickies	5	do.	Milky quartz grains; dark opaque inclusions	Clear quartz grains	Aggregates and inclusions of yellow unknown; zircon as inclusions; tourmaline(?); white "clay-mica"
S-48B-82	Oyster Point	Lancaster	do.	5	do.	Clear etched quartz grains; some milky quartz	—	Dark opaque inclusions; schorl tourmaline; yellow unknown inclusions; rutile(?)
S-49B-82	Neumans quarry	York	do.	34	do.	Milky and/or frosted quartz grains	Schorl tourmaline, inclusions to trace	Unknown yellow inclusions; zircon(?)
S-51B-82	Martinsburg, Tussey Mountain	Bedford	Silurian Tuscarora	13	do.	do.	—	Iron-stained quartz (rose and yellow); schorl tourmaline; minute dark inclusions
S-52B-82	Waggoners Gap	Cumberland	do.	10	do.	do.	—	Dark opaque unknown inclusions; iron-stained rose quartz; tourmaline(?)
S-54B-82	Harbison-Walker, Mount Union quarry	Huntingdon	do.	7	do.	do.	—	Iron-stained (rose and yellow) quartz; "clay-mica"; inclusions; tourmaline(?)
S-56B-82	Pennsylvania Glass Sand, Keystone Works	do.	Devonian Old Port, Ridgeley Member ("Oriskany")	19	do.	do.	—	Minute dark opaque inclusions; rare dark coatings(?)
S-56BB-82	do.	do.	do.	58	3 passes at 0° side slope and 1.5A	do.	—	Same as sample S-56B-82, but also contains tourmaline
S-61B-82	Firetower, Tuscarora Mountain	Franklin	Silurian Tuscarora	12	2 passes at 0.5° side slope and 1.5A	do.	—	Iron-stained (rose and yellow) quartz grains; minute dark inclusions
S-61BB-82	do.	do.	do.	57	4 passes at 0° side slope and 1.5A	do.	—	do.
S-64B-82	Cornog quartz vein	Chester	Cambrian(?) Quartz vein	1	2 passes at 0.5° side slope and 1.5A	Milky quartz fragments and clear grains	—	Minute dark opaque inclusions
S-65B-83	Weaver Gap, Rife Brothers quarry	Franklin	Silurian Tuscarora	Not available	do.	Milky and/or frosted quartz grains	—	Iron-stained (rose and yellow) quartz grains; minute dark inclusions
S-65B-83	do.	do.	do.	do.	4 passes at 0° side slope and 1.5A	do.	—	Same as sample S-65B-83, but also contains rare schorl tourmaline grains

[1] Magnetic beneficiation procedure includes one pass through the Frantz Isodynamic Magnetic Separator with a side slope setting of 2 degrees and 1 ampere to remove tramp iron. The front slope for all samples was a constant 15 degrees. All tests and procedures were undertaken following washing and acid baths.

CHEMICAL ANALYSES

The U.S. Bureau of Mines furnished preliminary semiquantitative elemental analyses for 79 silica samples and 5 standards. Approximately 5 to 10 g splits of minus-100-mesh pulps were submitted for each sample. The samples were digested in a mixture of HCl, HNO_3, HF, and $HClO_4$ and taken to perchloric fumes on a hot plate. The residues were put back in solution using dilute nitric acid and analyzed via inductively coupled plasma (ICP) spectrography for Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, and MnO. Possible alpha alumina (corundum) present in the ceramic pulverizing plates may not have been taken into solution using this procedure.

The Al_2O_3 and Fe_2O_3 ICP results reported for splits of two National Bureau of Standards glass-sand samples, submitted "blind" as controls, were unacceptable, and data for those elements are not included herein. Semiquantitative estimates of CaO, MgO, TiO_2, and MnO are included in Table 16. Sixty-seven "unknown" samples (samples S-1-81 through S-65BB-83), three sets of two "blind" glass-sand standards, "blind" replicates of samples S-51-82, S51B-82, and S-56-82, and two prepared samples were quantitatively analyzed for Al and Fe by Skyline Labs, Inc., using splits of prepared materials. These samples were digested in a mixture of HF, HNO_3, and $HClO_4$, and analyzed by atomic absorption spectroscopy. The precision and accuracy of the data reported for the reference samples are considered to be very good for the range of interest. Based on the low Al_2O_3 values reported for the NBS Standards, the reported Al_2O_3 values for the worst samples may be too low. However, this difficulty seems to exist only for highly aluminous samples beyond the range of interest.

TEST RESULTS

Quantitative atomic absorption results of analyses for Al_2O_3 and Fe_2O_3 are arranged by formation in Table 8. In this table, the best Al_2O_3 and Fe_2O_3 values are noted for each geologic system. Semiquantitative inductively coupled plasma analyses for MgO, CaO, TiO_2, and MnO, plus other pertinent information such as county, formation, sampled interval, and sample type, are appended as Tables 16 and 17.

As noted, atomic absorption analysis appears to provide very good accuracy when compared to certified silica standards for values less than 1,000 ppm (Table 9). Likewise, values less than 1,000 ppm are reasonably precise, based on duplicate samples. Minor-oxide values derived by inductively coupled plasma (ICP) analysis appear to waiver with respect to both accuracy and precision and should be interpreted with caution (Table 9). Ironically, in this regard, superbeneficiated samples appear less pure than beneficiated samples as a result of a precision problem induced because samples for ICP analyses were analyzed in separate batches at different times. Although every effort was made to obtain reliable and reproduci-

Table 8. *Results of Chemical Analyses[1] for Al_2O_3 and Fe_2O_3*

(Quantities are in parts per million unless otherwise indicated)

Geologic age / Geologic unit / Locality name	Sample numbers	As collected[2] Al_2O_3	As collected[2] Fe_2O_3	Beneficiated[3] Al_2O_3	Beneficiated[3] Fe_2O_3	Comments
PRECAMBRIAN(?) TO CAMBRIAN(?)						
Quartz veins						
Abandoned Summit Mining Company pit	S-26-81 S-26B-81	2,500	410	230	<15	3 feet (1 m) thick
Abandoned Moses Black	S-27-81 S-27B-81	1,200	1,300	80	<15	65 feet (20 m) thick
Abandoned Caledonia North	S-28-81 S-28B-81	1,100	690	90	<15	Float and dump
Abandoned Caledonia South	S-29-81 S-29B-81	590	540	90	<15	Float and pits
Dead Woman Hollow	S-30-81 S-30B-81	1,000	370	250	<15	10 feet (3 m) thick
Cornog	S-64-82 S-64B-82	570	710	60	<15	Flint dump

Table 8. *(Continued)*

Geologic age / Geologic unit / Locality name	Sample numbers	As collected[2] Al_2O_3	As collected[2] Fe_2O_3	Beneficiated[3] Al_2O_3	Beneficiated[3] Fe_2O_3	Comments
CAMBRIAN						
Hardyston Formation						
Berks Silica Sand quarry	S-1-81 S-1B-81	2.1%	1,100	680	100	Face
Chickies Formation						
Valley Forge Stone	S-46-82 S-46B-82	9,300	610	810	100	Mason sand
Oyster Point	S-48-82 S-48B-82	6,400	1,700	530	130	Face
Neumans quarry	S-49-82 S-49B-82	1.4%	3,000	2,800	600	Face and muck
Harpers Formation, Montalto Member						
Hempt Brothers, Toland	S-21-81 S-21B-81	1.7%	4,300	1,100	290	Aggregate stockpile
do.	S-22-81 S-22B-81	1.6%	2,600	450	130	Colluvium
State borrow pit, Pine Grove Furnace	S-23-81 S-23B-81	1.3%	1,400	250	100	Face
Antietam Formation						
Benders quarry, Mount Holly Springs	S-20-81 S-20B-81	8,500	660	570	100	White antiskid stockpile
Mount Cydonia Sand and Gravel Company, Plant No. 1	S-38-81 S-38B-81	2,500	190	250	70	White sand stockpile
do.	S-39-81 S-39B-81	4,200	760	230	40	Buff sand stockpile
SILURIAN						
Tuscarora Formation						
Martinsburg, Tussey Mountain	S-51-82 S-51B-82	5,100	760	420	110	Roadcut
Waggoners Gap	S-52-82 S-52B-82	6,800	940	600	160	Roadcut
Harbison-Walker, Mount Union quarry	S-54-82 S-54B-82	6,200	1,700	510	130	Refractory stockpile
Firetower, Tuscarora Mountain	S-61-82 S-61B-82	2,800	200	510	70	Outcrop
Weaver Gap, Rife Brothers quarry	S-65-83 S-65B-83	5,100	320	870	90	Face
DEVONIAN						
Old Port Formation, Ridgeley Member ("Oriskany")						
Pennsylvania Glass Sand, Keystone Works	S-56-82 S-56B-82	3,400	710	740	100	Core hole
Palmerton Formation						
Huss Contracting Company and Refractory Sand Company[4]	S-6-81 S-6B-81	1,400	600	230	140	Refractory sand stockpile
do.	S-8-81 S-8B-81	5,700	430	250	140	Face
Eastern Industries, Kunkletown	S-17-81 S-17B-81	6,600	470	300	170	Face
MISSISSIPPIAN						
Pocono Formation						
Lee Mountain	S-41-82 S-41B-82	7,400	1,600	360	60	Outcrop

Table 8. *(Continued)*

Geologic age / Geologic unit / Locality name	Sample numbers	As collected[2] Al$_2$O$_3$	As collected[2] Fe$_2$O$_3$	Beneficiated[3] Al$_2$O$_3$	Beneficiated[3] Fe$_2$O$_3$	Comments
PENNSYLVANIAN						
Lower Pottsville Group						
Warwick Sand Company	S-32-81 S-32B-81	3.4%	1,200	4,200	140	High-grade face
High Mountain quarry	S-35-81 S-35B-81	6,000	570	$\boxed{450}$	$\boxed{60}$	Stockpile
do.	S-36-81 S-36B-81	$\boxed{4,200}$	$\boxed{340}$	$\boxed{450}$	$\boxed{60}$	High-grade stockpile
Sunfish Pond	S-37-81 S-37B-81	1.9%	3,900	1,600	100	Float and outcrop

[1] See Tables 7, 17, and 18 for details of location, sampled interval, sample type, petrographic description, and mineralogy of magnetic fractions. See Figures 12 through 33 in Appendix for detailed location maps.

[2] All samples were washed with tap water in the laboratory prior to crushing or grinding.

[3] Beneficiation consisted of a 50 percent H_2SO_4 bath at 100 °C for 6 hours, followed by a 50 percent HCl bath at 55 °C for 6 hours, and magnetic separation.

[4] This sample was commercially washed and dried before stockpiling.

$\boxed{230 \quad 40}$ Box around value(s) indicates the lowest value for a given rock-stratigraphic system.

Table 9. *Comparison of Precision and Accuracy of Chemical Analyses by Atomic Absorption and Inductively Coupled Plasma Methods*

Sample type and designation	Results of chemical analyses[1] — Quantitative, Atomic absorption: Al$_2$O$_3$	Fe$_2$O$_3$	Semiquantitative, Inductively coupled plasma: MgO	CaO	TiO$_2$	MnO
NBS Certified Standard 81a	6,600	820	Not analyzed	Not analyzed	1,200	Not analyzed
Blind split of NBS 81a	3,800	810	130	51	490	18
do.	3,800	790	130	56	720	19
NBS Certified Standard 165a	590	120	Not analyzed	Not analyzed	110	Not analyzed
Blind split of NBS 165a	590	110	<4	37	61	3
do.	550	130	38	78	92	2
S-51-82	5,100	760	200	120	170	49
Blind duplicate of S-51-82	4,900	710	160	63	81	33
S-51B-82	420	110	22	69	55	3
Blind duplicate of S-51B-82	420	110	[2]5	48	130	3
S-56-82	3,400	710	—	—	—	—
Blind duplicate of S-56-82	3,200	710	—	—	—	—
Prepared standard	2,500	890	—	—	—	—
Blind duplicate of prepared standard	2,600	830	—	—	—	—
Prepared standard	250	70	—	—	—	—
Blind duplicate of prepared standard	250	60	—	—	—	—

[1] All chemical analyses are reported in parts per million unless otherwise indicated (100 ppm = 0.01 percent).

[2] Close to limit of detection.

ble test results, it is strongly recommended that all analyses be verified before planning major efforts based on these test results. Quantitative determinations of Al and Fe by atomic absorption spectroscopy are listed in Table 15 (appendix).

Sieve analyses were not attempted. Petrographic descriptions in Table 17 give some indication of the major grain size parameters for each sample locality. Some additional, previously published information is also included in the section on "Stratigraphic Framework of Sampled Intervals."

INTERPRETATIONS AND DISCUSSION OF TEST RESULTS

RANKING OF DATA

In Tables 10 and 11, as-collected samples and beneficiated samples, respectively, are listed in order of decreasing rank, as determined from the summed Fe_2O_3 and Al_2O_3 values. No superbeneficiated samples are included. Tables 12 and 13 rank the best Al_2O_3 values and the best Fe_2O_3 values for as-collected and beneficiated sedimentary samples, respectively, excluding quartz veins.

In general, most quartz veins are the purest silica sources tested with respect to combined Al_2O_3 and Fe_2O_3. The Cornog quartz vein occurs in apparent fault contact with the Cambrian Chickies quartzite, which at this location is iron stained and impure. However, this geologic setting (quartz veins in quartzite) might result in a purer end product (as suggested by the beneficiation results) than the other quartz veins, which are hosted in Precambrian metamorphosed acidic extrusive(?) volcanic rocks. Using the described beneficiation methods, iron contamination can almost be eliminated from quartz veins (Table 8). However, lowering the alumina value to less than 50 ppm appears to be difficult. This problem may be due to insoluble refractory compounds introduced during laboratory preparation (ceramic pulverizing plates). No aluminous phases ("mica") were observed in the magnetically beneficiated Cornog sample (S-64B-82).

R. H. Sullivan (personal communication, 1981) reported that in the South Mountain area the thinner quartz veins (3 feet (1 m) or less) are purer than the thicker quartz veins (usually greater than 10 feet (3 m)). Data do not support this and, in fact, the thinnest quartz vein (Summit Mining,

Table 10. *Ranking of Silica Analyses of As-Collected[1] Samples Based on the Summation of Al_2O_3 Plus Fe_2O_3*

Sample number	Locality name	County	Geologic age Formation	Summation of $Al_2O_3 + Fe_2O_3$ (ppm)[2]
S-29-81	Abandoned Caledonia South quartz veins	Franklin	Precambrian(?)	1,130
S-64-82	Cornog quartz vein	Chester	Cambrian(?)	1,280
S-30-81	Dead Woman Hollow quartz vein	Cumberland	Precambrian(?)	1,370
S-28-81	Abandoned Caledonia North quartz vein	Franklin	do.	1,790
S-6-81	Huss Contracting Company and Refractory Sand Company	Schuylkill	Devonian Palmerton	[3]2,000
S-27-81	Abandoned Moses Black quartz vein	Adams	Precambrian(?)	2,500
S-38-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Franklin	Cambrian Antietam	2,690
S-26-81	Abandoned Summit Mining Company pit	do.	Precambrian(?)	2,910

Table 10. *(Continued)*

Sample number	Locality name	County	Geologic age Formation	Summation of Al_2O_3 + Fe_2O_3 (ppm)[2]
S-61-82	Firetower, Tuscarora Mountain	Franklin	Silurian Tuscarora	3,000
S-56-82	Pennsylvania Glass Sand, Keystone Works	Huntingdon	Devonian Old Port, Ridgeley Member	4,110
S-36-81	High Mountain quarry	Tioga	Pennsylvanian Lower Pottsville Group	4,540
S-39-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Franklin	Cambrian Antietam	4,960
S-65-83	Weaver Gap, Rife Brothers quarry	do.	Silurian Tuscarora	5,420
S-51-82	Martinsburg, Tussey Mountain	Bedford	do.	5,860
S-8-81	Huss Contracting Company and Refractory Sand Company	Schuylkill	Devonian Palmerton	6,130
S-35-81	High Mountain quarry	Tioga	Pennsylvanian Lower Pottsville Group	6,570
S-17-81	Eastern Industries, Kunkletown	Monroe	Devonian Palmerton	7,070
S-52-82	Waggoners Gap	Cumberland	Silurian Tuscarora	7,740
S-54-82	Harbison-Walker, Mount Union quarry	Huntingdon	do.	7,900
S-48-82	Oyster Point	Lancaster	Cambrian Chickies	8,100
S-41-82	Lee Mountain	Columbia	Mississippian Pocono	9,000
S-20-81	Benders quarry, Mount Holly Springs	Cumberland	Cambrian Antietam	9,160
S-46-82	Valley Forge Stone	Chester	Cambrian Chickies	9,910
S-23-81	State borrow pit, Pine Grove Furnace	Cumberland	Cambrian Harpers, Mont-alto Member	14,400
S-49-82	Neumans quarry	York	Cambrian Chickies	17,000
S-22-81	Hempt Brothers, Toland	Cumberland	Cambrian Harpers, Mont-alto Member	18,600
S-21-81	do.	do.	—	21,300
S-1-81	Berks Silica Sand quarry	Berks	Cambrian Hardyston	22,100
S-37-81	Sunfish Pond	Bradford	Pennsylvanian Pottsville Group	22,900
S-32-81	Warwick Sand Company	Tioga	do.	35,200

[1] As-collected includes laboratory washing with tap water prior to grinding or crushing.
[2] 10,000 ppm = 1.0 percent.
[3] This sample was commercially washed and dried before stockpiling.

Table 11. *Ranking of Silica Analyses of Beneficiated[1] Samples Based on the Summation of Al_2O_3 Plus Fe_2O_3*

Sample number	Locality name	County	Geologic age Formation	Summation of $Al_2O_3 + Fe_2O_3$ (ppm)[2]
S-64B-82	Cornog quartz vein	Chester	Cambrian(?)	<75
S-27B-81	Abandoned Moses Black quartz vein	Adams	Precambrian(?)	<95
S-28B-81	Abandoned Caledonia North quartz vein	Franklin	do.	<105
S-29B-81	Abandoned Caledonia South quartz veins	do.	do.	<105
S-26B-81	Abandoned Summit Mining Company pit	Adams	do.	<245
S-30B-81	Dead Woman Hollow quartz vein	Cumberland	do.	<265
S-39B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Franklin	Cambrian Antietam	270
S-38B-81	do.	do.	do.	320
S-23B-81	State borrow pit, Pine Grove Furnace	Cumberland	Cambrian Harpers, Montalto Member	350
S-6B-81	Huss Contracting Company and Refractory Sand Company	Schuylkill	Devonian Palmerton	370
S-8B-81	do.	do.	do.	390
S-41B-82	Lee Mountain	Columbia	Mississippian Pocono	420
S-17B-81	Eastern Industries, Kunkletown	Monroe	Devonian Palmerton	470
S-35B-81	High Mountain quarry	Tioga	Pennsylvanian Lower Pottsville Group	510
S-36B-81	do.	do.	do.	510
S-51B-82	Martinsburg, Tussey Mountain	Bedford	Silurian Tuscarora	530
S-61B-82	Firetower, Tuscarora Mountain	Franklin	do.	580
S-22B-81	Hempt Brothers, Toland	Cumberland	Cambrian Harpers, Montalto Member	580
S-54B-82	Harbison-Walker, Mt. Union quarry	Huntingdon	Silurian Tuscarora	640
S-48B-82	Oyster Point	Lancaster	Cambrian Chickies	660
S-20B-81	Benders quarry, Mount Holly Springs	Cumberland	Cambrian Antietam	670
S-52B-82	Waggoners Gap	do.	Silurian Tuscarora	760
S-1B-81	Berks Silica Sand quarry	Berks	Cambrian Hardyston	780
S-56B-82	Pennsylvania Glass Sand, Keystone Works	Huntingdon	Devonian Old Port, Ridgeley Member	840

Table 11. *(Continued)*

Sample number	Locality name	County	Geologic age Formation	Summation of $Al_2O_3 + Fe_2O_3$ (ppm)[2]
S-46B-82	Valley Forge Stone	Chester	Cambrian Chickies	910
S-65B-83	Weaver Gap, Rife Brothers quarry	Franklin	Silurian Tuscarora	960
S-21B-81	Hempt Brothers, Toland	Cumberland	Cambrian Harpers, Mont-alto Member	1,390
S-37B-81	Sunfish Pond	Bradford	Pennsylvanian Lower Pottsville Group	1,700
S-49B-82	Neumans quarry	York	Cambrian Chickies	3,400
S-32B-81	Warwick Sand Company	Tioga	Pennsylvanian Lower Pottsville Group	4,340

[1]Beneficiation consisted of a 50 percent H_2SO_4 bath at 100 °C for 6 hours, followed by a 50 percent HCl bath at 55 °C for 6 hours, and magnetic separation.
[2]100 ppm = 0.01 percent.

sample S-26-81) apparently contains the greatest amount of as-collected Al_2O_3.

The Cambrian Antietam Formation, particularly at the Mount Cydonia operation, is the purest sedimentary deposit investigated, both on an as-collected as well as a beneficiated basis (Tables 8 and 16).[1] Material collected from the buff-colored sand stockpile at the Mount Cydonia operation contains more Al_2O_3 and Fe_2O_3 than the white sand, but appears to respond better to the beneficiation procedure than the white sand (Table 8). The mining interval of the buff sand may represent a weathered, oxidized zone, with the Al_2O_3 and Fe_2O_3 in acid-soluble forms. This phenomenon was also noted in unpublished chemical analyses of a Devonian sequence in the Commonwealth.

A few as-collected samples from the Antietam, Palmerton, Old Port, and Tuscarora Formations, as well as the Pennsylvanian lower Pottsville Group, contain less than 0.5 percent Al_2O_3. The same formations (except the Old Port, a glass sand) yield some typical as-collected Fe_2O_3 values of 0.05 percent or less (Table 8).

Composite samples of as-collected silica having apparent SiO_2 values of 99 percent or more, based on the summation of Al_2O_3 and Fe_2O_3, include (1) all quartz veins; (2) certain samples from the Cambrian Antietam and Chickies Formations; (3) all samples from the Silurian Tuscarora Formation, but in particular Cotter's (1982, 1983) "basal horizontally laminated lithofacies" (see page 7); (4) a sample from the Devonian Ridgeley Member of the Old Port Formation ("Oriskany") and samples from the Palmerton Formation; (5) a sample from the Mississippian Pocono Formation; and (6) certain samples from the Pennsylvanian lower Pottsville Group. Some as-collected composite samples from the Cambrian Hardyston Formation and the Pennsylvanian Pottsville Group have apparent SiO_2 values of between 98 and 97 percent, based on the summation of Al_2O_3 plus Fe_2O_3, and some as-collected composite samples from the Pottsville Group have apparent values of less than 97 percent.

Beneficiated samples from the Antietam, Palmerton, Harpers, Pocono, and Tuscarora Formations, as well as from the lower Pottsville Group, yielded Al_2O_3 values of less than 0.05 percent. Fe_2O_3 values of 0.01 percent or less were obtained from some beneficiated samples collected from the Antietam, Pocono, Tuscarora, Harpers, Hardyston, Old Port, and Chickies Formations, as well as from the lower Pottsville Group. The Lee Mountain, Mississippian Pocono sample cleaned up very well and had only 7 percent magnetic beneficiation loss.

[1]One commercially washed refractory stockpile sample from Huss Contracting Company and Refractory Sand Company has lower as-collected Al_2O_3 values than samples from Mount Cydonia. However, an as-collected face sample washed in the laboratory from Huss shows considerably higher alumina values.

Table 12. *Ranking of the 10 Lowest Al_2O_3 and Fe_2O_3 Values for As-Collected[1] Sedimentary Silica Samples*

Sample number	Locality name	Geologic age Formation	Al_2O_3 (ppm)	Sample number	Locality name	Geologic age Formation	Fe_2O_3 (ppm)
[2]S-6-81	Huss Contracting Company and Refractory Sand Company	Devonian Palmerton	1,400	S-38-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam	190
S-38-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam	2,500	S-61-82	Firetower, Tuscarora Mountain	Silurian Tuscarora	200
S-61-82	Firetower, Tuscarora Mountain	Silurian Tuscarora	2,800	S-65-83	Weaver Gap, Rife Brothers quarry	do.	320
S-56-82	Pennsylvania Glass Sand, Keystone Works	Devonian Old Port, Ridgeley Member	3,400	S-36-81	High Mountain quarry	Pennsylvanian Lower Pottsville Group	340
S-39-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam	4,200	S-8-81	Huss Contracting Company and Refractory Sand Company	Devonian Palmerton	430
S-36-81	High Mountain quarry	Pennsylvanian Lower Pottsville Group	4,200	S-17-81	Eastern Industries, Kunkletown	do.	470
S-65-83	Weaver Gap, Rife Brothers quarry	Silurian Tuscarora	5,100	S-35-81	High Mountain quarry	Pennsylvanian Lower Pottsville Group	570
S-51-82	Martinsburg, Tussey Mountain	do.	5,100	[2]S-6-81	Huss Contracting Company and Refractory Sand Company	Devonian Palmerton	600
S-8-81	Huss Contracting Company and Refractory Sand Company	Devonian Palmerton	5,700	S-46-82	Valley Forge Stone	Cambrian Chickies	610
S-35-81	High Mountain quarry	Pennsylvanian Lower Pottsville Group	6,000	S-20-81	Benders quarry, Mount Holly Springs	Cambrian Antietam	660

[1]As-collected includes laboratory washing prior to grinding or crushing.
[2]This sample is a commercially washed and dried refractory product.

Table 13. *Ranking of the 12 Lowest Al_2O_3 and Fe_2O_3 Values for Beneficiated[1] Sedimentary Silica Samples*

Sample number	Locality name	Geologic age Formation	Al_2O_3 (ppm)
S-39B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam	230
S-6B-81	Huss Contracting Company and Refractory Sand Company	Devonian Palmerton	230
S-38B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam	250
S-23B-81	State borrow pit, Pine Grove Furnace	Cambrian Harpers, Montalto Member	250
S-8B-81	Huss Contracting Company and Refractory Sand Company	Devonian Palmerton	250
S-17B-81	Eastern Industries, Kunkletown	do.	300
S-41B-82	Lee Mountain	Mississippian Pocono	360
S-51B-82	Martinsburg, Tussey Mountain	Silurian Tuscarora	420
S-22B-81	Hempt Brothers, Toland	Cambrian Harpers, Montalto Member	450
S-35B-81 S-36B-81	High Mountain quarry	Pennsylvanian Lower Pottsville Group	450
S-54B-82	Harbison-Walker, Mount Union quarry	Silurian Tuscarora	510
S-61B-82	Firetower, Tuscarora Mountain	do.	510

Sample number	Locality name	Geologic age Formation	Fe_2O_3 (ppm)
S-39B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam	40
S-41B-82	Lee Mountain	Mississippian Pocono	60
S-35B-81 S-36B-81	High Mountain quarry	Pennsylvanian Lower Pottsville Group	60
S-38B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam	70
S-61B-82	Firetower, Tuscarora Mountain	Silurian Tuscarora	70
S-65B-82	Weaver Gap, Rife Brothers quarry	do.	90
S-23B-81	State borrow pit, Pine Grove Furnace	Cambrian Harpers, Montalto Member	100
S-20B-81	Benders quarry	Cambrian Antietam	100
S-1B-81	Berks Silica Sand quarry	Cambrian Hardyston	100
S-56B-82	Pennsylvania Glass Sand, Keystone Works	Devonian Old Port, Ridgeley Member	100
S-46B-82	Valley Forge Stone	Cambrian Chickies	100
S-37B-81	Sunfish Pond	Pennsylvanian Lower Pottsville Group	100

[1]Beneficiation consisted of a 50 percent H_2SO_4 bath at 100 °C for 6 hours, followed by a 50 percent HCl bath at 55 °C for 6 hours, and magnetic separation.

SOME TYPICAL CHEMICAL COMPOSITIONS AND POTENTIAL PRODUCT USES

Some typical chemical compositions for raw silica used in manufactured products are shown in Table 14. White or flint glass is a loose term that can be applied to any crushed quartz sand. The container industry generally uses this term to designate colorless glass, but it has also been used to refer to high-refraction, low-dispersion optical glass (Thrush, 1968). Refractory ganister is generally defined as a fine-grained quartzite which is usually crushed into angular fragments for use in the manufacture of silica brick. Refractory pebble, on the other hand, generally refers to smooth, rounded quartzose granules and pebbles (2 to 64 mm) used to manufacture the same product. This is distinguished from Brazilian pebble, which generally refers to quartz crystals. Metallurgical quartz is used as a source of silicon in the manufacture of ferrosilicon alloys. The ability of the metallurgical quartz or silica rock to withstand thermal stress is a primary consideration aside from high-purity and coarsely sized material. High-purity silicon production is a complex process in which commercial silicon metal is used as a nutrient material (I. A. Kunasz, personal communication, 1982).

The hydrothermal synthesis of quartz produces crystals that can be cut and used in applications requiring high quality and specific crystal orientation. The raw material is a grade of high-purity natural quartz crystal called "lasca," which is derived from the Portuguese word for splinter or slice (G. H. Edwards, personal communication, 1984). An oriented "seed crystal" of quartz is suspended in an alkaline solution in an autoclave, and the lasca nutrient is placed in the bottom of the autoclave. A temperature gradient is created, so that in the warmer bottom zone natural quartz is slowly dissolved and is carried by convection currents to the cooler upper zone. The temperature in the upper zone is below that at which the silica can stay in solution, and it is deposited on the seed crystal. Figure 6 is a generalized cross-sectional diagram of a typical commercial autoclave.

Lasca

There are no as-collected or beneficiated silica sources in Pennsylvania that compare in purity with the existing quartz-crystal lasca sources from Brazil or Arkansas. Quartz veins sampled from Cornog in Chester County and the abandoned Moses Black pit in Adams County are the best with respect to beneficiated Al_2O_3 and Fe_2O_3 values. The Al_2O_3 values of these samples may be near the lowest values attainable using the Survey's available preparation procedures. Residual refractory material from crushing and pulverizing equipment could be present (see the section on "Sample Preparation").

Glass Sand

The glass-container industry generally does not directly specify an upper limit with respect to Al_2O_3 content, only a minimum SiO_2 value for the purer high-silica sands. The critical consideration is that the Al_2O_3 value remain constant and not

Table 14. *Typical Chemical Composition of Raw Silica Used in Some Products*

Product	Al_2O_3 (ppm)[1]	Fe_2O_3 (ppm)[1]	Source
Synthetic quartz crystals; electronic and optical uses; specialty glass	20–40	2–8	Unpublished
White or flint glass	≤800	≤250	Mills (1975)
Refractory pebble (washed sandstone from processed stockpile)	≤1,400	≤600	Pennsylvania Geological Survey analysis
Silicon production	<1,500	<1,000	D. Kirstein (personal communication, 1983)
Metallurgical quartz	≤1,500	≤1,000	Murphy (1975)
Yellow or amber glass	≤2,500	≤1,500	Mills (1975)
Refractory ganister (quartzite from processed mill-feed stockpile)	≤6,200	≤1,700	Pennsylvania Geological Survey analysis

[1]1,000 ppm = 0.1 percent.

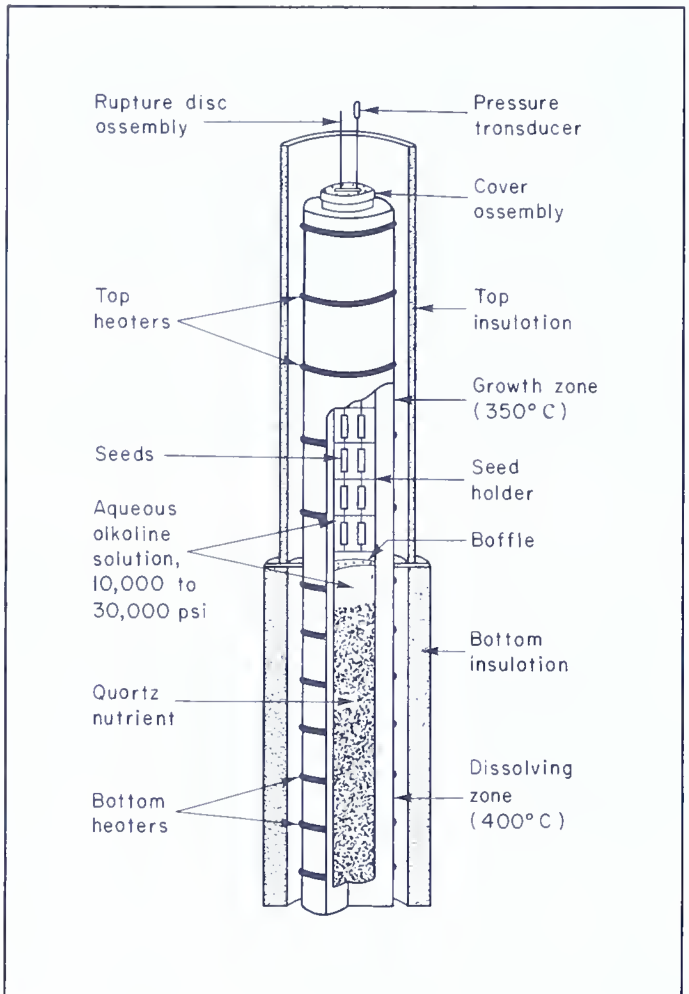


Figure 6. Cross section of a typical commercial quartz-growing autoclave (from Motorola Inc., 1980). Crystal growing generally requires a month or more.

waiver within given limits. Theoretically, the upper Al_2O_3 limit for a high-silica sand ($\geq$ 99.5 percent SiO_2) cannot exceed 5,000 ppm, whereas feldspathic glass sands may have between about 3 and 9 percent Al_2O_3 (F. J. DeNapoli, personal communication, 1984). Most published sources list typical Al_2O_3 values of between 800 ppm and 1,000 ppm for flint or first-quality white glass sand (Mills, 1975; Ceramic Data Book, 1983).

A favorable glass-sand size gradation is generally about 100 percent minus-28 mesh and about 95 percent plus-140 mesh. In an effort to save energy, future trends might specify finer gradations. Gradations with most of the material in the 50-mesh range are becoming more desirable as new glass-making processes replace older, more energy intensive plants, particularly in the specialty glass industry (F. Preston, personal communication, 1981).

The as-collected samples from the Antietam white sand stockpile at Mount Cydonia and the Tuscarora outcrop at the Firetower locality both contain less Fe_2O_3 than typical compositions of white glass sand (Tables 8 and 14). The white sand stockpile at Mount Cydonia contains major to minor white clay-mica, which appears to be readily washable. The Tuscarora in general appears to be too indurated to have serious glass-sand potential in the near future. The Weaver Gap sample, however, appears to break around grain boundaries more readily than other Tuscarora samples.

Many as-collected samples meet or are lower than the typical Fe_2O_3 value for yellow glass, such as certain samples from the Cambrian Hardyston, Chickies, Harpers, and Antietam Formations, all Silurian basal Tuscarora samples, all Devonian samples, and most Pennsylvanian lower Pottsville Group samples analyzed (Tables 8 and 14). Potential yellow-glass sources are limited to the Cambrian Montalto Member of the Harpers Formation, the Antietam Formation, the producing Devonian Ridgeley Member of the Old Port Formation ("Oriskany"), and possibly Pennsylvanian clastics if large tonnages could be identified.

All beneficiated sedimentary samples are lower in Fe_2O_3 than the typical composition of yellow glass sand. Other untested chemical as well as physical characteristics of these samples must be evaluated to determine whether they are suitable for this product. Serious consideration should be given to the Cambrian Antietam Formation and Harpers Formation (Montalto Member), as well as the traditional producer, the Devonian Old Port Formation. Locally, the Pennsylvanian lower Pottsville Group may hold some minor glass-sand potential such as at the High Mountain quarry in western Tioga County. However, standard size gradations for the manufacture of glass may be expensive to produce from the generally poorly sorted conglomeratic sandstone at this locality. Based on Al_2O_3 and Fe_2O_3 analyses, the Lee Mountain outcrop of the Mississippian Pocono Formation responds well to beneficiation. However, coarseness and variation in grain size exclude it from consideration for glass sand.

Potential beneficiated white-glass sources other than the established Devonian Old Port Formation are the Cambrian Antietam Formation and Harpers Formation (Montalto Member), and the Pennsylvanian lower Pottsville Group. The Silurian Tuscarora Formation has low Al_2O_3 and Fe_2O_3 values. However, the well-indurated silica cement would make appropriate sizing very difficult and expensive.

Metallurgical Quartz

The chemical compositions of the analyzed as-collected samples from the abandoned Caledonia North, Caledonia South, and Cornog quartz veins, as well as the outcropping Dead Woman Hollow quartz vein, appear to indicate a potential for use as a metallurgical quartz. However, available tonnages of these sources are limited. None of the well-indurated sedimentary samples meet typical chemical compositions for metallurgical quartz. Furthermore, because of the large fragments needed for this application (generally 4 inches by 1/2 inch), beneficiation of samples does not appear practical.

Silicon

Current typical compositions for silicon production are not readily obtainable from industry. D. Kirstein of the West Virginia Geological Survey (personal communication, 1983) indicated that a plant in that state uses a raw material with chemical specifications exceeding metallurgical-grade quartz. However, presumably smaller size gradations than are used for metallurgical-grade quartz would be acceptable, inferring that beneficiated sources might be considered. Other than veins, only the as-collected commercially washed stockpile of refractory sand from the Palmerton Formation appears to meet the poorly defined requirements for silicon production. Commercial washing of the raw product might reduce the Al_2O_3 values below the typical composition for some samples that already have low Fe_2O_3 values.

Refractory

Locally, the "basal horizontally laminated lithofacies" (see page 7) of the Silurian Tuscarora Formation (Cotter, 1982, 1983) contains less Fe_2O_3 than the known producing ganister quarries, which are predominantly developed in fluvial cycles higher in the formation. This basal part of the Tuscarora contains silica capable of producing a superior refractory brick with little waste. Locally, the Cambrian Antietam forms a white, hard, vitreous quartzite that is probably similar in chemical composition to the white sand reported as analysis S-38-81. The Cambrian Chickies Formation in Lancaster and Chester Counties might also hold some potential as a ganister source, as might the Cambrian Hardyston Formation in Berks County if the Al_2O_3 could be easily washed out. The Pennsylvanian lower Pottsville Group conglomerates may locally produce refractory pebble. The coarser material from the High Mountain quarry in Tioga County is one such potential source.

Proppant

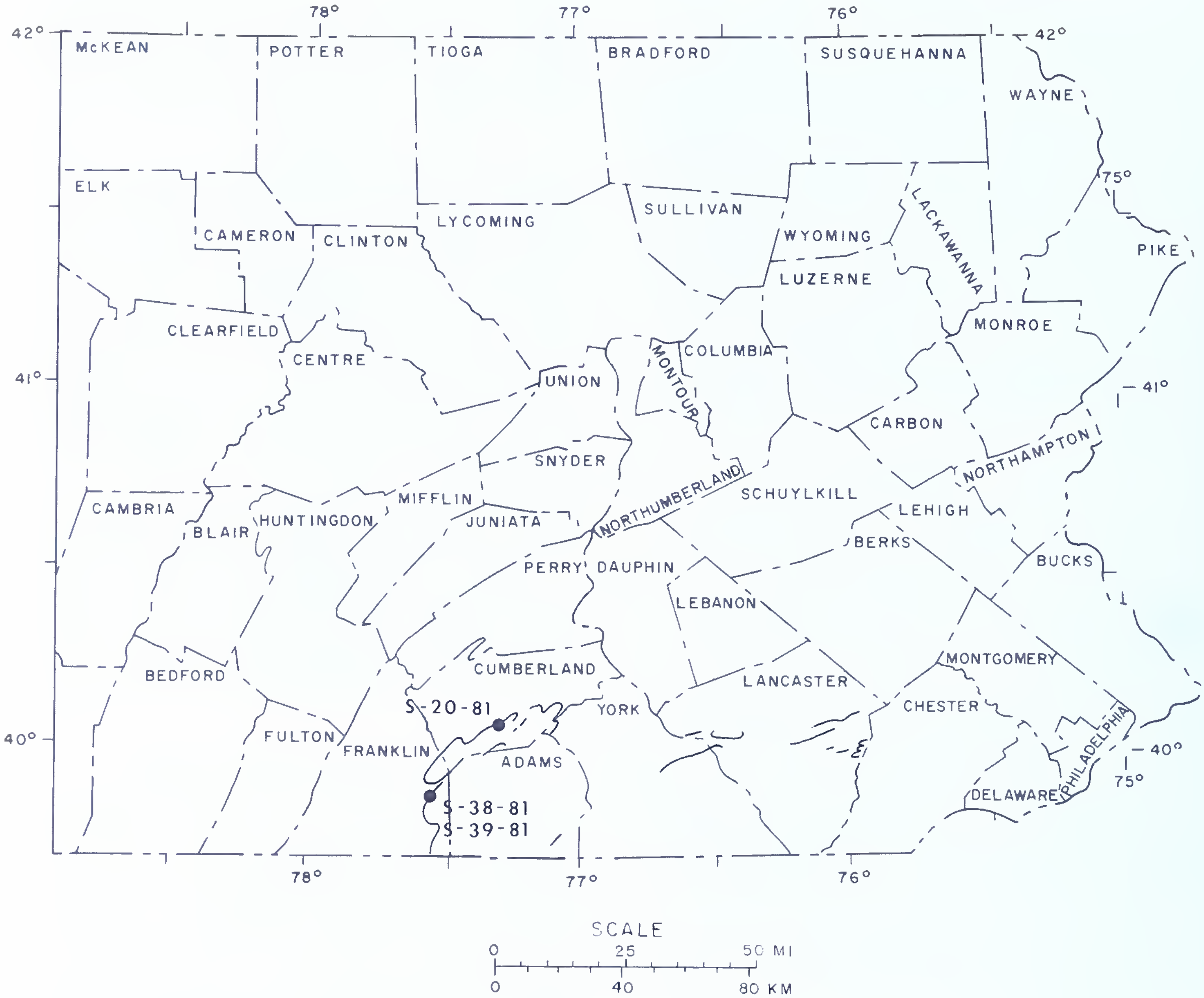
The most common and popular gradations of hydraulic fracturing sand (proppant) for oil field service are the 12/20 mesh (1.68 to 0.84 mm), 20/40 mesh (0.84 to 0.42 mm), and 40/70 mesh (0.42 to 0.21 mm) (American Petroleum Institute, 1983). The Devonian Palmerton Formation might produce a coarse-sized proppant, the Devonian "Oriskany" might produce a range of popular gradations, and the Cambrian Antietam, where friable, might have potential as a medium-gradation proppant.

Besides gradation, other characteristics such as sphericity, roundness, acid solubility, turbidity, soft-particle content, and crush resistance should be evaluated in considering the potential of any naturally occurring sand proppant. The American Petroleum Institute (1983) has recently established recommended procedures for testing sand proppants.

REGIONAL GEOLOGIC TRENDS

The Cambrian Antietam Formation appears to be purest in southeastern Franklin County, in the southern portion of the South Mountain anticlinorium. The as-collected Fe_2O_3 value of white sand from Mount Cydonia is lower than the as-collected values from any of the quartz veins analyzed. A considerable amount of white clay-mica was rinsed out of this as-collected sample during laboratory preparation. Figure 7 shows a generalized outcrop belt of the Antietam Formation illustrating sample locations and results of preliminary Al_2O_3 and Fe_2O_3 analyses. The Antietam has not been evaluated in York and Lancaster Counties, but observation suggests it is less pure there. Apparently the Erwin Formation, equivalent to the Antietam (Milici and others, 1963; Berg and others, 1983), becomes less pure to the south of Pennsylvania. Harris (1972) and Sweet (1981) reported Al_2O_3 and Fe_2O_3 values from Virginia that generally exceed several thousand parts per million each.

The Cambrian Hardyston Formation appears to be purest (about 97.5 percent SiO_2) in one of many imbricate thrust sheets in central Berks County (sample S-1-81). Other locations were investigated but not sampled because of their obvious low purity. Kaolinitic clays are a major Al_2O_3 con-



Sample number	Locality name	Type of as-collected sample	Al_2O_3 (ppm)	Fe_2O_3 (ppm)
S-38-81	Mount Cydonia	White sand stockpile	2,500	190
S-39-81	do.	Buff sand stockpile	4,200	760
S-20-81	Benders	White antiskid stockpile	8,500	660

Figure 7. Generalized outcrop-belt map of the Cambrian Antietam Formation.

taminant locally and also occur as bedded horizons up to 25 feet (8 m) thick within the lower part of the sequence (Berkheiser and Smith, 1984).

The Cambrian Chickies Formation appears to increase in Fe_2O_3 content from east to west through Lancaster and eastern York Counties. Besides having high iron contents, this formation in York County also has a high alumina content. Most quarries investigated were not sampled due to obvious high concentrations of iron, mica, and tourmaline. Apparently, eastern Lancaster and northern Chester Counties contain local sites of cleaner, better sorted sand deposition due to a higher energy coastal marine environment of deposition.

The Montalto Member of the Harpers Formation is restricted in outcrop to the South Mountain anticlinorium in Cumberland, Franklin, Adams, and York Counties. The Harpers Formation occurs stratigraphically beneath the overlying Cambrian Antietam Formation. Total silica contents range between about 97.5 and 98.5 percent, and further investigation is warranted. Major contaminants include clay-mica and oxides of iron.

In recent investigations, Cotter (1982, 1983) identified a locally distinctive basal unit of the Silurian Tuscarora Formation. This nearly pure quartzarenite, named by Cotter the "basal horizontally laminated lithofacies,"[1] reaches a maximum thickness of about 100 feet (30 m) in southeastern Blair County. Ninety-foot (27-m) sections have also been measured in northern Cumberland and Franklin Counties (Figure 2). Silica contents appear highest in the Franklin-Fulton County area (Firetower and Weaver Gap), as illustrated in Figure 8. Thicknesses of this formation greater than 50 feet (15 m) with low Al_2O_3 and Fe_2O_3 contents may extend into Maryland and West Virginia. Arkle and Hunter (1957) reported values of Al_2O_3 as low as 2,600 ppm and Fe_2O_3 as low as 280 ppm from channel samples of portions of the basal Tuscarora in West Virginia. Harris (1972) and Sweet (1981) reported less pure values of several thousand parts per million for both Al_2O_3 and Fe_2O_3 from hand and composite samples taken from portions of this formation in Virginia.

The Ridgeley Member of the Old Port Formation is the producing "Oriskany" glass sand in Pennsylvania. Figure 9 illustrates the generalized outcrop pattern and general areas believed to contain 50 feet (15 m) or more of sandstone. The area containing the least amount of Fe_2O_3 appears to be Sand Ridge, the existing producing district, where total thicknesses of about 190 feet (60 m) are not uncommon. Fettke (1919) reported that Sand Ridge is by far the most important source of glass sand in the "Oriskany" outcrop belt. He also reported higher as-collected iron values of 1,000 ppm on Warrior Ridge about 1/2 mile (1 km) south of the gap at Tatesville, Bedford County. This site is about 10 miles (15 km) south of where de Witt (1974) reported measuring an impressive 350-foot (100-m) "Oriskany" section on the same ridge, which suggests that thickness increases to the southwest and Fe_2O_3 contents should be investigated.

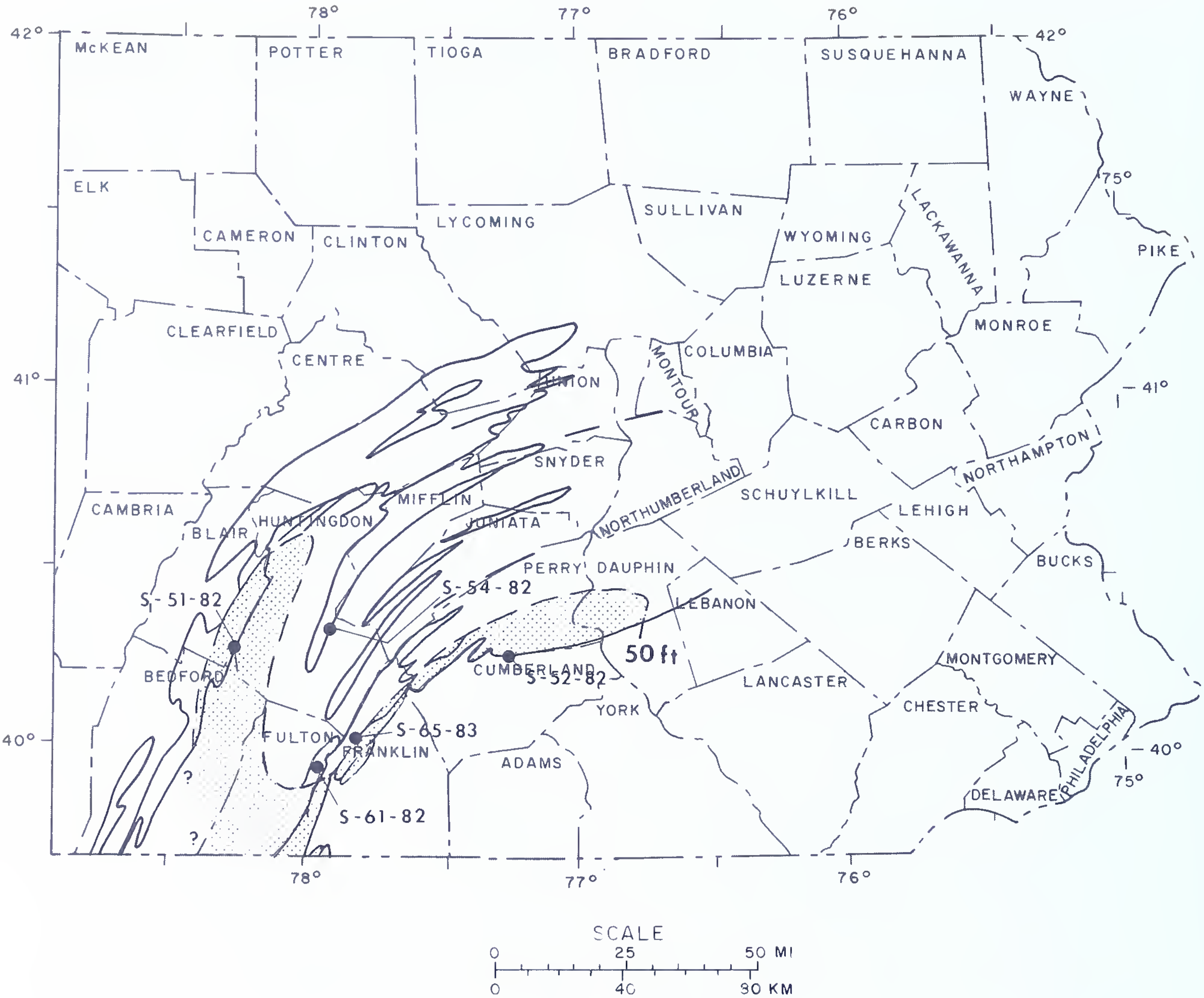
Figure 10 shows the generalized outcrop pattern of the Devonian Palmerton Formation in Schuylkill, Carbon, and Northampton Counties. It appears that this sequence of generally coarse grained sandstone and conglomerate is more pure near the southwestern and northeastern portions of the outcrop belt. Sevon (1970) believed the local occurrence of high iron corresponded to the distribution of the overlying Hazard paint ore bed, which he theorized was leached and redeposited in the Palmerton. Sevon noted local hematite cement and concentrations of hematite along bedding and joint planes, usually in the lower part of the sequence. See Figure 5 for an isopach map of the Palmerton, which appears to be best developed in southeastern Carbon County and southwestern Monroe County.

Few data are available for the Mississippian Pocono Formation (sample S-42-82). A composite representing only about 10 feet (3 m) of outcrop was examined in an area that contained moderate amounts of iron staining (total silica about 99 percent). However, total Fe_2O_3 content after beneficiation was reduced to only 60 ppm. Perhaps further consideration should be given to what, in the field, appears to be a "dirty sandstone."

A generalized, partial outcrop pattern of the Pennsylvanian lower Pottsville Group in eastern Pennsylvania is shown in Figure 11. The purest Pennsylvanian sequence studied occurs in western Tioga County (samples S-35-81 and S-36-81). Here the $\leq$0.5 mm quartz grains display striking euhedral silica crystal overgrowths. Up to 80 percent of this finer sized fraction has euhedral overgrowths. Euhedral brookite and anatase have also been identified, suggesting that the silica purity may be related to an aqueous-phase remobilization rather than source areas and depositional environment.

Based on examination of numerous quartz-rich outcrops and quarries, it is apparent that near-surface leaching may play a role in the natural beneficiation of quartzose outcrops. The scale of the phenomenon may be related to the type and degree of cementation. Smith and Berkheiser (1983) noted small-scale concentrically zoned rocks cropping out as ledges in the generally well indurated basal Tuscarora. It was postulated that this was a moving front of leaching and concentration via capillary attraction through time. Similar small-scale features are particularly well preserved at Sunfish Pond in Bradford County (sample S-37-81), where a well-cemented conglomeratic sandstone crops out. Here, casual examination of the outcrop would lead to erroneous conclusions. An outer, white leached zone up to 1 cm thick generally surrounds a core of limonitic- and hematitic-stained sandstone. Locally less well cemented sandstone, such as portions of the Cambrian Antietam at Mount Cydonia in Franklin County and Benders white quarry in Cumberland County, portions of the Devonian Palmerton Formation in eastern Pennsylvania, and the upper portion of the Devonian "Oriskany" in the central part of

[1] The lowest unit of the Silurian Tuscarora Formation that is characterized by horizontal bedding laminae (see page 7).



EXPLANATION

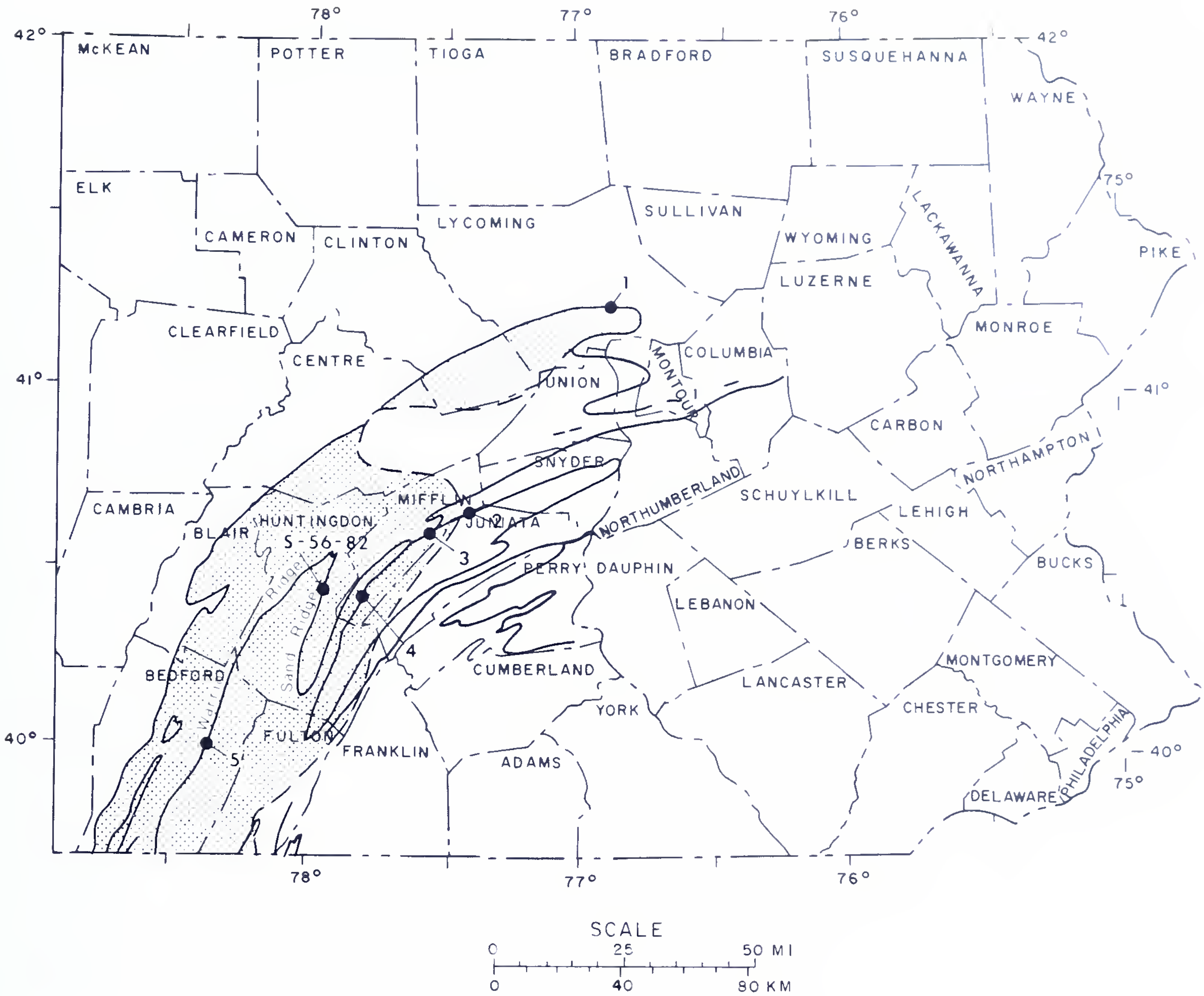
Area believed to contain 50 feet (15 m) or more of Cotter's (1982, 1983) "basal horizontally laminated lithofacies." This unit is characterized as a well-indurated, supermature quartz arenite having conspicuous horizontal laminae and is locally present at the base of the Tuscarora Formation.

Sample number	*Locality name*	*Type of as-collected sample*	*Al_2O_3 (ppm)*	*Fe_2O_3 (ppm)*
S-51-82	Martinsburg	Roadcut (105 ft; 32 m)	5,100	760
S-52-82	Waggoners Gap	Roadcut (54 ft; 16 m)	6,800	940
S-54-82*	Harbison-Walker	Processed stockpile	*6,200	*1,700
S-61-82	Firetower	Outcrop (49 ft; 15 m)	2,800	200
S-65-83	Weaver Gap	Face (25 ft; 8 m)	5,100	320

*Sample is from a higher unit of the Silurian Tuscarora Formation.

Figure 8. Generalized outcrop-belt map of the Silurian Tuscarora Formation.

the state, contain bleached or leached areas that are usually friable. This may represent a genetically similar but grander scale of natural beneficiation that is much more extensive due to the locally poor lithification of the sequence. In most of these large-scale examples, contiguous sequences of highly iron stained, well-indurated quartzites are present.



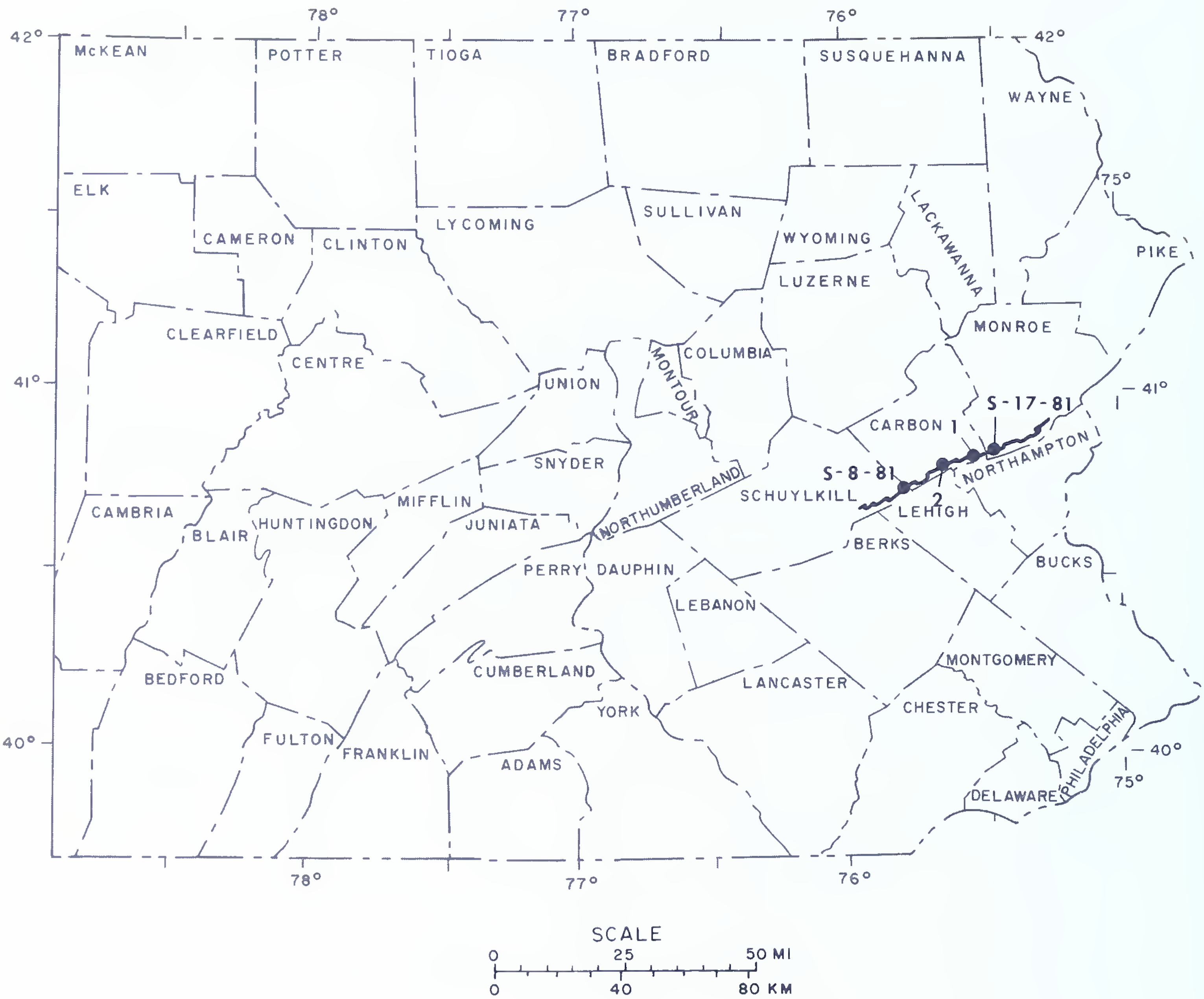
EXPLANATION

Area believed to contain 50 feet (15 m) or more of Ridgeley Member of the Old Port Formation ("Oriskany"). Data compiled from Figure 3.

Sample number	*Lacality name*	*Type af as-callected sample*	Al_2O_3	Fe_2O_3
S-56-82	Pennsylvania Glass Sand	Corehole (140 ft; 42 m)	3,400 ppm	710 ppm
1	Fram Wells and Bucek (1980)		—	2.1%
2	From Fettke (1919)		—	1,800 ppm
3	da.		—	1,100 ppm
4	do.		—	1,700 ppm
	Fram Fettke (1919). Washed No. 1 sand, Hatfield Works		—	600 ppm
5	From Fettke (1919)		—	1,000 ppm

Figure 9. Generalized outcrop-belt map of the Devonian Ridgeley Member of the Old Port Formation ("Oriskany").

Probably unrelated to the above, but important in terms of iron concentration, are what appear to be trapped hydrocarbons in some quartzite zones in the Old Port and Tuscarora Formations. Hydrocarbon-like residues were observed in the Tuscarora at Susquehanna Gap. R. C. Smith, II (personal communication, 1984) reported similar material in the Tuscarora east of Mapleton at

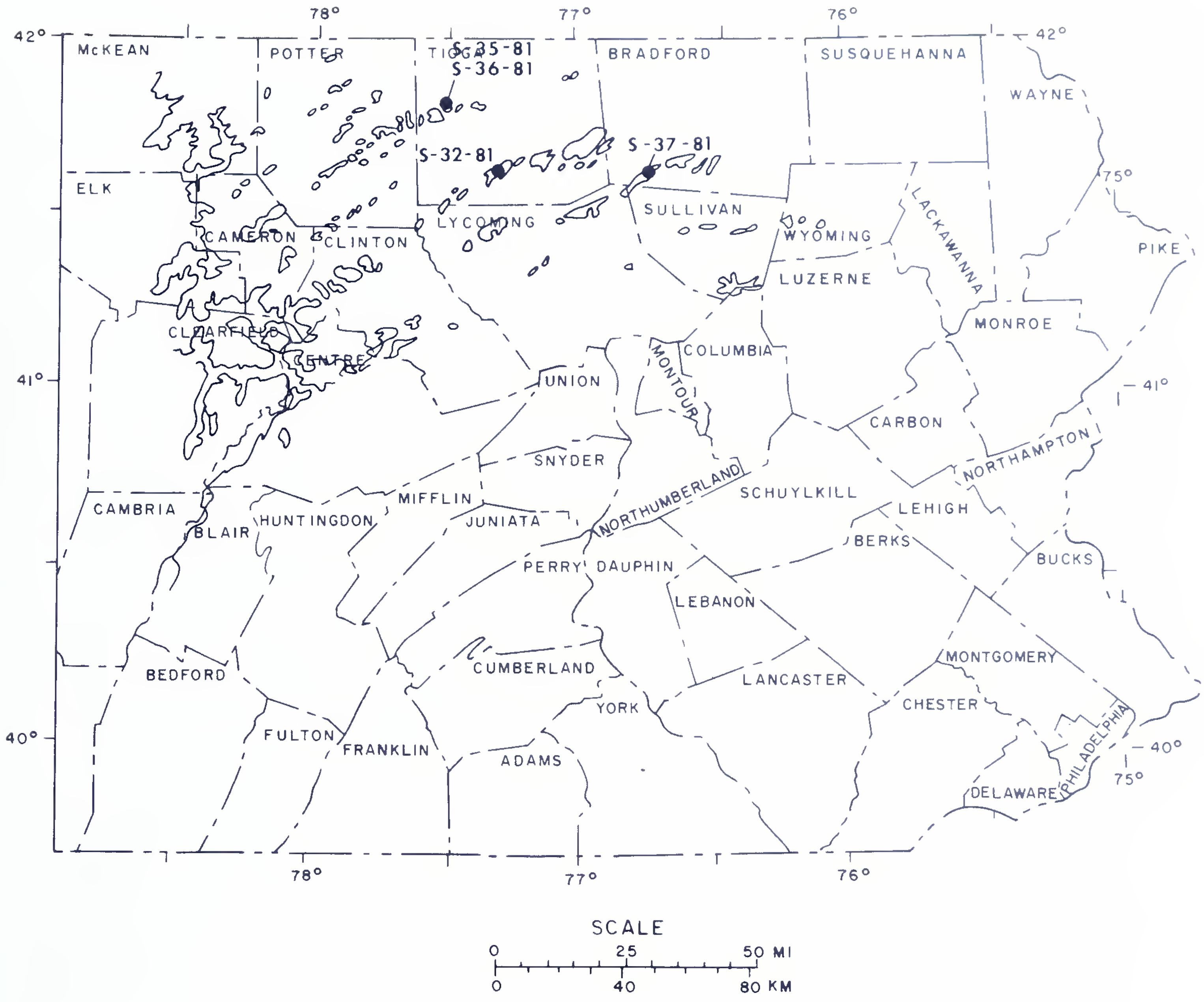


Sample number	Locality name	Type of as-collected sample	Al_2O_3 (ppm)	Fe_2O_3 (ppm)
S-8-81	Huss	Selected face (90 ft; 26 m)	5,700	430
S-17-81	Eastern	High-grade face (26 ft; 8 m)	6,600	470
1	Little Gap	From Sevon (1970)	1,200	7,300
	do.	do.	2,300	7,900
2	Alliance	None	Visually very high	

Figure 10. Generalized outcrop-belt map of the Devonian Palmerton Formation in eastern Pennsylvania.

Jacks Narrows near the west end of the railroad cut. Fettke (1919) noted "blueish gray vitreous quartzite" locally occurring on Sand Ridge in Huntingdon County. Chemical analysis of the bluish-gray quartzite, compared with sand derived from this quartzite by weathering, yielded 250 percent more Fe_2O_3 (Fettke, 1919). From this data and examination of this phenomenon elsewhere, it appears that carbonaceous material was trapped in well-cemented zones that provided local reducing sites where pyrite and other iron sulfides could precipitate.

Finally, the variability of some massive vitreous quartzite zones in some sequences does not appear



Sample number	Locality name	Type of as-collected sample	Al_2O_3	Fe_2O_3
S-32-81	Warwick Sand	High-grade face (25 ft; 8 m)	3.4%	1,200 ppm
S-35-81	High Mountain quarry	Stockpile	6,000 ppm	570 ppm
S-36-81	do.	High-graded stockpile	4,200 ppm	340 ppm
S-37-81	Sunfish Pond	Float and outcrop	1.9%	3,900 ppm

Figure 11. Generalized outcrop-belt map of the Pennsylvanian lower Pottsville Group in north-central Pennsylvania.

to be continuously bed-parallel. Silicification, induration, and mineralization may be locally related to tectonic events. Wallace de Witt (personal communication, 1983) noted massive zones of quartzite in the Tuscarora where bedding was not discernible in an area of known faulting. Cross-faults in the Valley and Ridge physiographic province might be sites of local intense silicification, brecciation, and deleterious sulfide mineralization, such as that in the Hares Valley and Milesburg Gap areas (Smith, 1977).

CONCLUSIONS

PURITY

(1) A composite, as-collected[1] stockpile sample (S–38–81) from the Cambrian Antietam Formation in Franklin County yielded the lowest (less than 200 ppm) as-collected Fe_2O_3 value of all samples tested.

(2) Large quartz veins (generally greater than 10 feet (3 m) in width and some up to 65 feet (20 m) in width) have apparent as-collected SiO_2 values of 99.75 percent or more, based on the summation of Al_2O_3 plus Fe_2O_3.

(3) Composite samples of as-collected silica having apparent SiO_2 values of 99.5 percent or more, based on the summation of Al_2O_3 and Fe_2O_3, include (a) all quartz veins; (b) white and buff sand stockpiles from the Cambrian Antietam Formation in Franklin County; (c) a processed refractory-sand stockpile from the Devonian Palmerton Formation; (d) the basal portion of the Silurian Tuscarora Formation at a site in Franklin County; (e) the Devonian Old Port ("Oriskany") in Huntingdon County (an established glass-sand producer); and (f) a select high-grade sample of the Pennsylvanian lower Pottsville Group in western Tioga County.

(4) In addition to the above, composite samples of as-collected silica having apparent SiO_2 values of 99 percent or more based on the summation of Al_2O_3 and Fe_2O_3 include (a) a white antiskid stockpile of the Cambrian Antietam Formation in Cumberland County; (b) the Cambrian Chickies Formation in Chester and Lancaster Counties; (c) all samples from the Silurian Tuscarora Formation, but in particular Cotter's (1982, 1983) "basal horizontally laminated lithofacies"; (d) the Devonian Palmerton Formation in Schuylkill and Monroe Counties; (e) a sample from the Mississippian Pocono Formation in Columbia County; and (f) the Pennsylvanian lower Pottsville Group in western Tioga County.

(5) The most common impurities in quartz veins generally are chlorite, muscovite, specular hematite, and unspecified oxides of iron. The most common impurities in the sedimentary sequences generally are white clay-mica, oxides of iron, tourmaline, and minute opaque inclusions.

[1] "As-collected" composite silica samples were washed in the laboratory. Washing consisted of agitation of uncrushed chips in a plastic tub until the rinse water became relatively clear.

BENEFICIATION

(1) Beneficiation tests, consisting of 100°C 50 percent H_2SO_4 baths for 6 hours, 55°C 50 percent HCl baths for 6 hours, and magnetic beneficiation which averaged less than 9 percent loss, effectively removed Al_2O_3 and Fe_2O_3. All samples beneficiated improved in apparent SiO_2 purity. Values of at least 99.5 percent SiO_2, based on the summation of Al_2O_3 plus Fe_2O_3, were obtained for all samples tested.

(2) Superbeneficiation, which consisted of the same acid bath procedure but more intense magnetic separation averaging 55 percent loss, showed, in general, no significant improvement over less intense magnetic separation.

(3) Beneficiation improved the purity of a quartz vein sample occurring in quartzite from Chester County from 1,230 ppm total Al_2O_3 plus Fe_2O_3 to less than 75 ppm.

(4) Beneficiated samples having Al_2O_3 values of 450 ppm or less include samples from all of the quartz veins and certain samples from (a) the Cambrian Antietam Formation and the Montalto Member of the Harpers Formation; (b) the Silurian basal Tuscarora Formation; (c) the Devonian Palmerton Formation; (d) the Mississippian Pocono Formation; and (e) the Pennsylvanian lower Pottsville Group.

(5) Beneficiated samples having Fe_2O_3 values of 100 ppm or less include samples from all of the quartz veins and certain samples from (a) the Cambrian Antietam Formation, Montalto Member of the Harpers Formation, and Chickies and Hardyston Formations; (b) the Silurian basal Tuscarora Formation; (c) the Devonian Ridgeley Member of the Old Port Formation ("Oriskany"); (d) the Mississippian Pocono Formation; and (e) the Pennsylvanian lower Pottsville Group.

(6) Numerous as-collected, low-iron sedimentary silica deposits appear to have potential for improving the Al_2O_3 values simply through commercial washing.

SOME POTENTIAL USES

(1) No as-collected samples meet the typical Al_2O_3 or Fe_2O_3 values for lasca use (nutrient

for growing electronic-grade cultured quartz crystals). A beneficiated sample from a quartz vein occurring in quartzite from Chester County, Pennsylvania, probably is within the designated Fe_2O_3 limits but is about 20 ppm too high with respect to Al_2O_3 values. Some of this Al_2O_3 may have been introduced during pulverizing.

(2) The most promising as-collected potential new source of white glass and yellow glass is the Cambrian Antietam Formation. The Devonian Ridgeley Member of the Old Port Formation, which was also studied, is already an established source of raw material for this industry.

(3) A production stockpile from the Cambrian Antietam Formation yielded the purest chemical analysis for as-collected and beneficiated samples from a sedimentary deposit. This formation appears to have exploration potential for a variety of high-purity silica end-uses in Pennsylvania.

(4) Most large quartz veins appear to have small potential tonnage for metallurgical quartz use. Selective mining and probable hand sorting would be necessary to maintain a quality product. However, other physical and chemical characteristics also must be evaluated, especially susceptibility to thermal shock.

(5) Cotter's (1982, 1983) ''basal horizontally laminated lithofacies'' of the Silurian Tuscarora Formation is the best ganister target in the state with respect to purity and tonnage available. Currently, there is no known refractory production from this basal sequence. If this unit were not so well indurated (with resulting crushing difficulties), it could have other potential uses.

(6) The Devonian Palmerton Formation currently is a source of refractory pebble. Locally, sequences in the Pennsylvanian lower Pottsville Group also have some similar potential and have had historic production.

(7) The purer sedimentary sequences, such as the Cambrian Antietam, the Silurian Tuscarora, and the Devonian Old Port Formation, as well as the quartz veins, may have some potential as feedstock sources for the production of silicon.

(8) The Devonian Palmerton Formation appears to have some potential as a 12/20-mesh hydraulic fracturing sand (proppant). Other formations that have potential for proppant include the Cambrian Antietam and the Devonian Old Port Formations where they are friable.

POTENTIAL RESOURCES AVAILABLE

(1) Although relatively pure quartz veins up to 65 feet (20 m) thick have been sampled, their potential uses are restricted by the small tonnages potentially available to mining.

(2) The Ridgeley Member of the Old Port Formation represents the largest potentially minable high-silica resource within the Commonwealth. Stratigraphic intervals of more than 100 feet (30 m) are not uncommon throughout much of Mifflin, Huntingdon, Bedford, and Fulton Counties. As much as 350 feet (100 m) has been reported on Warrior Ridge in Bedford County (de Witt, 1974). However, data from Fettke (1919) indicate that rocks from this area may not match the purity of those from Sand Ridge further to the northeast.

(3) Potentially minable stratigraphic thicknesses of 50 feet (15 m) or more of Cotter's (1982, 1983) ''basal horizontally laminated'' zone of the Silurian Tuscarora Formation occur locally in Huntingdon, Blair, Bedford, Fulton, Franklin, Perry, and Cumberland Counties and represent a major silica resource.

(4) The Cambrian Antietam Formation is the purest sedimentary silica deposit studied. It is restricted to the South Mountain anticlinorium in Franklin, Cumberland, York, and Adams Counties. Detailed physical and chemical characteristics, such as thickness of lithology (quartzite versus friable sandstone), variation in chemistry, and lateral continuity, should be evaluated. Selective mining for fine aggregate is currently being practiced at several localities, and analyzed samples came from these stockpiles.

(5) It would be difficult to identify large, thick areas that have consistent physical and chemical characteristics based on the tentatively proposed alluvial depositional environment of the Pennsylvanian lower Pottsville Group in northern Pennsylvania. Grain size, silica content, and ore geometry may be too variable to consider for most larger tonnage operations.

(6) Formations such as the Cambrian Antietam, Devonian Palmerton, Silurian Tuscarora, and Devonian Old Port that were deposited

in beach, nearshore, and nearshore-bar environments of deposition appear to be the best sedimentary targets for high-purity silica, and represent the largest minable resources within the Commonwealth.

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APPENDIX

Table 15. *Quantitative Al and Fe Determinations by Atomic Absorption Spectroscopy*

(Analyses by Skyline Labs, Inc., Wheat Ridge, Colorado)

Sample number	Al (ppm)[1]	Fe (ppm)[1]
S-1-81	11,000	760
S-1B-81	360	70
S-6-81	720	420
S-6B-81	120	100
S-6BB-81	130	90
S-8-81	3,000	300
S-8B-81	130	100
S-17-81	3,500	330
S-17B-81	160	120
S-20-81	4,500	460
S-20B-81	300	70
S-20BB-81	270	70
S-21-81	9,200	3,000
S-21B-81	570	200
S-22-81	8,600	1,800
S-22B-81	240	90
S-23-81	6,700	1,000
S-23B-81	130	70
S-23BB-81	140	60
S-26-81	1,300	290
S-26B-1	120	<10
S-27-81	620	880
S-27B-81	40	<10
S-27BB-81	40	<10
S-28-81	560	480
S-28B-81	50	<10
S-29-81	310	380
S-29B-81	50	<10
S-30-81	550	260
S-30B-81	130	<10
S-32-81	18,000	840
S-32B-81	2,200	100

Table 15. *(Continued)*

Sample number	Al (ppm)[1]	Fe (ppm)[1]
S-35-81	3,200	400
S-35B-81	240	40
S-36-81	2,200	240
S-36B-81	240	40
S-37-81	10,000	2,700
S-37B-81	870	70
S-38-81	1,300	130
S-38B-81	130	50
S-39-81	2,200	530
S-39B-81	120	30
S-41-82	3,900	1,100
S-41B-82	190	40
S-46-82	4,900	430
S-46B-82	430	70
S-48-82	3,400	1,200
S-48B-82	280	90
S-49-82	7,500	2,100
S-49B-82	1,500	420
S-51-82	2,700	530
S-51B-82	220	80
S-52-82	3,600	660
S-52B-82	320	110
S-54-82	3,300	1,200
S-54B-82	270	90
S-56-82	1,800	500
S-56B-82	390	70
S-56BB-82	140	50
S-61-82	1,500	140
S-61B-82	270	50
S-61BB-82	250	50
S-64-82	300	500
S-64B-82	30	<10
S-65-83	2,700	320
S-65B-83	460	60
S-65BB-83	320	60

[1] 1,000 ppm = 0.1 percent.

Table 16. *Chemical Analyses for As-Collected, Beneficiated, and Superbeneficiated Samples*

Sample number	Locality name	County	Geologic age Formation	Sample type[2]	Chemical analyses[1] Quantitative Atomic absorption Al_2O_3	Fe$_2$O$_3$	Semiquantitative Inductively coupled plasma MgO	CaO	TiO_2	MnO
S-1-81	Berks Silica Sand quarry	Berks	Cambrian Hardyston	C	2.1%	1,100	510	65	690	26
S-1B-81	do.	do.	do.	B	680	100	< 4	< 10	370	3
S-6-81	Huss Contracting Company and Refractory Sand Company	Schuylkill	Devonian Palmerton	C	1,400	600	39	110	20	6
S-6B-81	do.	do.	do.	B	230	140	< 4	[3]13	17	2
S-6BB-81	do.	do.	do.	SB	250	130	28	73	33	1.4
S-8-81	do.	do.	do.	C	5,700	430	75	69	190	5
S-8B-81	do.	do.	do.	B	250	140	< 4	[3]15	19	3
S-17-81	Eastern Industries, Kunkletown	Monroe	do.	C	6,600	470	58	62	220	6
S-17B-81	do.	do.	do.	B	300	170	< 4	[3]10	24	3
S-20-81	Benders quarry, Mount Holly Springs	Cumberland	Cambrian Antietam	C	8,500	660	440	33	320	3
S-20B-81	do.	do.	do.	B	570	100	< 4	< 10	84	2
S-20BB-81	do.	do.	do.	SB	510	100	42	59	160	1.6
S-21-81	Hempt Brothers, Toland	do.	Cambrian Harpers, Montalto Member	C	1.7%	4,300	1,400	39	550	28
S-21B-81	do.	do.	do.	B	1,100	290	80	< 10	130	2
S-22-81	do.	do.	do.	C	1.6%	2,600	930	28	610	50
S-22B-81	do.	do.	do.	B	450	130	[2]8	< 10	80	2
S-23-81	State borrow pit, Pine Grove Furnace	do.	do.	C	1.3%	1,400	630	45	400	12
S-23B-81	do.	do.	do.	B	250	100	12	33	120	< .1
S-23BB-81	do.	do.	do.	SB	260	90	30	36	140	1.6
S-26-81	Abandoned Summit Mining Company pit	Adams	Precambrian(?) Quartz vein	C	2,500	410	51	54	33	31
S-26B-81	do.	do.	do.	B	230	< 15	< 4	26	< 1	2

S-27-81	Abandoned Moses Black quartz vein	do.	do.	C	1,200	1,300	120	70	12	56
S-27B-81	do.	do.	do.	B	80	< 15	< 4	[3]13	< 1	< .1
S-27BB-81	do.	do.	do.	SB	80	< 15	12	27	8.8	1.6
S-28-81	Abandoned Caledonia North quartz vein	Franklin	do.	C	1,100	690	71	40	16	50
S-28B-81	do.	do.	do.	B	90	< 15	< 4	[3]11	5	2
S-29-81	Abandoned Caledonia South quartz veins	do.	do.	C	590	540	47	30	13	42
S-29B-81	do.	do.	do.	B	90	< 15	[3]10	[3]19	13	3
S-30-81	Dead Woman Hollow quartz vein	Cumberland	do.	C	1,000	370	74	100	19	54
S-30B-81	do.	do.	do.	B	250	< 15	[3]5	14	[3]1	[3]2
S-32-81	Warwick Sand Company	Tioga	Pennsylvanian Lower Potts-ville Group	C	3.4%	1,200	480	100	690	19
S-32B-81	do.	do.	do.	B	4,200	140	53	33	210	3
S-35-81	High Mountain quarry	do.	do.	C	6,000	570	160	61	270	20
S-35B-81	do.	do.	do.	B	450	60	[3]5	[3]13	21	< .1
S-36-81	do.	do.	do.	C	4,200	340	120	51	250	14
S-36B-81	do.	do.	do.	B	450	60	27	26	70	3
S-37-81	Sunfish Pond	Bradford	do.	C	1.9%	3,900	380	80	570	98
S-37B-81	do.	do.	do.	B	1,600	100	26	52	130	3
S-38-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Franklin	Cambrian Antietam	C	2,500	190	140	110	120	3
S-38B-81	do.	do.	do.	B	250	70	15	42	74	3
S-39-81	do.	do.	do.	C	4,200	760	200	96	170	3
S-39B-81	do.	do.	do.	B	230	40	10	32	73	2
S-41-82	Lee Mountain	Columbia	Mississippian Pocono, lower half	C	7,400	1,600	250	70	100	24
S-41B-82	do.	do.	do.	B	360	60	22	42	39	3
S-46-82	Valley Forge Stone	Chester	Cambrian Chickies	C	9,300	610	300	80	620	22
S-46B-82	do.	do.	do.	B	810	100	26	[3]18	170	2

Table 16. (Continued)

Sample number	Locality name	County	Geologic age Formation	Sample type[2]	Chemical analyses[1] Quantitative Atomic absorption Al_2O_3	Chemical analyses[1] Quantitative Atomic absorption Fe_2O_3	Chemical analyses[1] Semiquantitative Inductively coupled plasma MgO	Chemical analyses[1] Semiquantitative Inductively coupled plasma CaO	Chemical analyses[1] Semiquantitative Inductively coupled plasma TiO_2	Chemical analyses[1] Semiquantitative Inductively coupled plasma MnO
S-48-82	Oyster Point	Lancaster	Chickies	C	6,400	1,700	350	45	340	15
S-48B-82	do.	do.	do.	B	530	130	42	[3]14	140	2
S-49-82	Neumans quarry	York	do.	C	1.4%	3,000	800	74	570	56
S-49B-82	do.	do.	do.	B	2,800	600	200	51	130	3
S-51-82	Martinsburg, Tussey Mountain	Bedford	Silurian Tuscarora	C	5,100	760	200	120	170	49
S-51B-82	do.	do.	do.	B	420	110	22	69	55	3
S-52-82	Waggoners Gap	Cumberland	do.	C	6,800	940	330	310	130	31
S-52B-82	do.	do.	do.	B	600	160	14	44	90	3
S-54-82	Harbison-Walker, Mt. Union quarry	Huntingdon	do.	C	6,200	1,700	400	62	220	61
S-54B-82	do.	do.	do.	B	510	130	22	38	79	3
S-56-82	Pennsylvania Glass Sand, Keystone Works	do.	Devonian Old Port, Ridgeley Member ("Oriskany")	C	3,400	710	170	150	96	24
S-56B-82	do.	do.	do.	B	740	100	< 4	43	51	< .1
S-56BB-82	do.	do.	do.	SB	260	70	23	64	100	1.6
S-61-82	Firetower, Tuscarora Mountain	Franklin	Silurian Tuscarora	C	2,800	200	66	[3]24	180	7
S-61B-82	do.	do.	do.	B	510	70	< 4	< 10	28	< .1
S-61BB-82	do.	do.	do.	SB	470	70	29	49	120	2.0
S-64-82	Cornog quartz vein	Chester	Cambrian(?)	C	570	710	69	39	9	33
S-64B-82	do.	do.	do.	B	60	< 15	< 4	< 10	< 1	< .1
S-65-83	Weaver Gap, Rife Brothers quarry	Franklin	Silurian Tuscarora	C	5,100	320	51	170	320	18
S-65B-83	do.	do.	do.	B	870	90	34	37	190	2.2
S-65BB-83	do.	do.	do.	SB	600	90	22	30	190	1.9

[1] All chemical analyses are reported in parts per million unless otherwise noted; 100 ppm = 0.01 percent.

[2] B, beneficiated; C, composite as collected; SB, superbeneficiated.

[3] Close to limit of detection.

Table 17. ***Petrographic Descriptions of Samples and Some Highest Potential Uses[1] Based on Chemical Analyses***

(See Table 14 for typical chemical compositions of raw materials for some silica products)

Sample numbers	Name and location	Geologic age Formation Attitude of bed or vein	Petrographic description	Sampled interval and type	Highest potential uses "as-collected"	Highest potential uses after "beneficiation"	Comments
S-1-81 S-1B-81	Berks Silica Sand Products Alsace Township Berks County SE 1/4 Temple 7-1/2-minute quadrangle 40°23′47″N/75°52′32″W	Cambrian Hardyston N65°E, 72°NW	Quartzite, light-gray to very light gray, coarse-grained (1.0 to 0.5 mm); rounded to subrounded quartz grains; abundant white kaolinitic(?) clay as fracture filling; some friable beds; some opaque grains; minor local limonitic staining; locally vitreous.	Face composite, easternmost face, lowest lift; 70-foot (21-m) selected stratigraphic interval; high-grade of face.	—	Chemically TiO_2 appears high for white glass. Gradation and induration not compatible.	Simple commercial washing may significantly lower "as-collected" Al_2O_3 values. Potential ganister source.
S-6-81 S-6B-81 S-6BB-81	Huss Contracting Company and Refractory Sand Company, Inc. West Penn Township Schuylkill County NE 1/4 New Tripoli 7-1/2-minute quadrangle 40°44′30″N/75°47′00″W	Devonian Palmerton	Sandstone, very light gray to yellowish-gray, coarse-grained (up to 3 mm); angular to subrounded, individual quartz grains are milky in appearance; some limonitic staining; clay coating on quartz grains(?).	Composite of washed refractory-pebble stockpile.	Sets Pennsylvania standard for refractory pebble. Possible 12/20-mesh proppant.	Chemically meets typical analyses for white glass; however, gradation is not compatible.	This is a commercially washed refractory product.
S-8-81 S-8B-81	do.	do.	Sandstone and conglomerate, very light gray to white, very coarse grained (pebbles up to 5 mm); rounded to subrounded grains; can be friable; most grains have milky appearance; rare dark smoky quartz grains and dark opaque grains; some limonitic staining; leached zone(?).	Face composite, west face, main development bench; selected 90-foot (27-m) interval.	Possible 12/20-mesh proppant; chemically near typical analyses for refractory pebble.	do.	Represents a raw refractory pebble before commercial washing.
S-17-81 S-17B-81	Eastern Industries, Inc., Kunkletown Eldred Township Monroe County NE 1/4 Kunkletown 7-1/2-minute quadrangle 40°50′50″N/75°26′12″W	do.	Sandstone, very light gray, coarse- to very coarse grained (1 to 5 mm), subrounded to rounded; can be friable with local zones of vitreous quartzite; most quartz grains have milky appearance; some iron staining; some white clay(?) locally.	Face composite, easternmost face, first lift; 26-foot (8-m) selected stratigraphic interval; high-grade of face.	do.	do.	Simple commercial washing may significantly lower "as-collected" Al_2O_3 values.
S-20-81 S-20B-81 S-20BB-81	R. A. Bender and Son Dickinson Township Cumberland County NW 1/4 Mt. Holly Springs 7-1/2-minute quadrangle 40°06′18″N/77°12′45″W	Cambrian Antietam N82°E, 47°NW	Quartzite, white to yellowish-gray, medium- to coarse-grained (0.5 mm), rounded to subrounded, vitreous; locally abundant limonitic and hematitic staining on fracture surfaces; rare black opaque grain.	Composite stockpile, white quarry, antiskid stockpile.	Potential for a feldspathic yellow glass. Possible proppant where weathered.	Chemically and physically appears to meet typical analyses for white glass.	Both chemically and physically appears to be a good beneficiated glass-sand target.

Table 17. (Continued)

Sample numbers	Name and location	Geologic age Formation Attitude of bed or vein	Petrographic description	Sampled interval and type	Highest potential uses "as-collected"	Highest potential uses after "beneficiation"	Comments
S-21-81 S-21B-81	Hempt Brothers Inc., Toland Dickinson Township Cumberland County NW 1/4 Mt. Holly Springs 7-1/2-minute quadrangle 40°04′30″N/77°13′00″W	Cambrian Harpers, Montalto Member	Quartzite, very light gray to light-gray, coarse-grained (0.5 to 1.0 mm); rounded to subrounded grains; vitreous; dark opaque grains common; some limonitic and hematitic staining; rare thin quartz veins; rare pink rose quartz grains.	Composite stockpile, 1B aggregate stockpile processed from clay dumps.	—	Chemically meets typical refractory-pebble analyses; gradation not compatible.	Cleans up surprisingly well.
S-22-81 S-22B-81	Hempt Brothers Inc., Toland Dickinson Township Cumberland County NW 1/4 Mt. Holly Springs 7-1/2-minute quadrangle 40°05′03″N/77°12′42″W	do.	Quartzite, light-gray to very light gray, coarse-grained (0.5 to 1.0 mm), rounded to subrounded, vitreous; dark opaque grains common; some pink rose quartz; some white "clay-mica" as coatings and grains; local limonitic staining.	Composite grab sample from stripped area on Mount Holly, 145-foot (44-m) sampled traverse across strike.	—	Chemically meets typical analyses for white glass.	Cleans up surprisingly well. Might have potential as a glass-sand target.
S-23-81 S-23B-81 S-23BB-81	State borrow pit Pine Grove Furnace Cooke Township Cumberland County SE 1/4 Dickinson 7-1/2-minute quadrangle 40°01′23″N/77°18′40″W	do.	Quartzite, white to grayish-orange, medium-grained (0.25 to 0.5 mm), subrounded to rounded, vitreous to granular; some white "clay-mica" coatings; rare dark opaque grains; limonitic staining common; near mapped fault contact, shear zone(?).	Composite face sample.	Potential for a feldspathic yellow glass.	do.	Cleans up surprisingly well. Might have potential as a glass-sand target.
S-26-81 S-26B-81	Abandoned Summit Mining Company pit Menallen Township Adams County SE 1/4 Dickinson 7-1/2-minute quadrangle 40°00′09″N/77°17′06″W	Precambrian(?) quartz vein Country rock foliation: N55°E, 30°SE	Vein quartz, white to very light gray, milky in appearance; some specular hematite on fracture surfaces; some local limonitic staining; rare kaolinized potassium feldspar inclusion; rare chlorite or muscovite inclusions.	Composite face sample of 3-foot- (1-m-) thick quartz vein in meta-rhyolite quarry.	Chemically meets typical analyses for metallurgical quartz.	Chemically meets typical analyses for white glass; however, gradation is not compatible.	Possible best use for most quartz veins is metallurgical silica. Low tonnage available.
S-27-81 S-27B-81 S-27BB-81	Abandoned Moses Black quartz vein Menallen Township Adams County SE 1/4 Dickinson 7-1/2-minute quadrangle 40°00′26″N/77°17′31″W	Precambrian(?) quartz vein Country rock foliation: vertical(?)	Vein quartz, white, milky in appearance; specular hematite on fracture surfaces and locally concentrated in face in zones up to 6 inches (15 cm) in diameter; chlorite inclusions and veinlets locally common.	Composite face and float samples over an approximately 500 foot (150 m) trend. Abandoned pit with face approximately 65 feet (20 m) wide, 32 feet (10 m) deep, and 120 feet (37 m) long.	Chemically close to typical analyses for metallurgical quartz.	do.	Largest quartz vein studied. Flint was reported to have been shipped to Aspers for making china.
S-28-81 S-28B-81	Abandoned Caledonia North quartz vein Greene Township Franklin County SW 1/4 Caledonia 7-1/2-minute quadrangle 39°53′47″N/77°28′22″W	do.	Vein quartz, very light gray; locally clear quartz; some fragments have sheared appearance; some limonitic staining; some specular hematite on fracture surfaces; rare buff-colored feldspar(?).	Composite float from overgrown workings and mine dump. Dimension of workings: approximately 12 feet (4 m) deep, approximately 20 feet (6 m) wide, and approximately 350 feet (110 m) long.	Chemically meets typical analyses for silicon production.	do.	Low tonnage available.

S-29-81 S-29B-81	Abandoned Caledonia South quartz veins and prospect pits Greene Township Franklin County SW 1/4 Caledonia 7-1/2-minute quadrangle 39°53′30″N/77°28′36″W	do.	Vein quartz, very light gray to white; some clear quartz; some fragments have sheared appearance; minor limonitic staining; some specular hematite on fracture surfaces; rare sericite; rare buff-colored feldspar(?).	Composite of float from numerous small prospect pits in a 1,500-foot (460-m) area.	Chemically meets typical analyses for refractory pebble; however, gradation is not compatible.	do.	do.
S-30-81 S-30B-81	Dead Woman Hollow Southampton Township Cumberland County SW 1/4 Dickinson 7-1/2-minute quadrangle 40°00′10″N/77°21′31″W	do.	Vein quartz, very light gray to white; milky quartz; minor specular hematite on fracture surface; rare sericite; rare limonitic staining; some host-rock inclusions.	Composite of float for about 700 feet (215 m) along trend. Vein is about 10 feet (3 m) wide.	do.	do.	do.
S-32-81 S-32B-81	Warwick Sand Company Delmar Township Tioga County SE 1/4 Antrim 7-1/2-minute quadrangle 41°38′17″N/77°18′33″W	Pennsylvanian Lower Pottsville Group Subhorizontal	Sandstone, light-gray to very light gray, some yellowish gray; medium grained (up to 0.5 mm), containing some pebbles up to 5 mm; subrounded; some black opaque grains; muscovite flakes common; white "clay-mica" coatings and grains; carbonaceous and organic debris along bedding planes; locally abundant hematite and limonite along fracture surfaces; laminated and crossbedded.	High-grade selected face composite; about 25 feet (8 m) of stratigraphic section on upper lift, southwest face.	Potential for a feldspathic yellow glass. Proppant.	Chemically Fe_2O_3 meets typical white-glass analyses.	Al_2O_3 values excessive for most uses. This quarry allegedly was a source of container glass(?).
S-35-81 S-35B-81	High Mountain quarry Clymer Township Tioga County NW 1/4 Asaph 7-1/2-minute quadrangle 41°49′18″N/77°29′38″W	do.	Sandstone and conglomerate, white, some yellowish gray and moderate reddish brown; medium-grained (0.5 mm) and smaller; containing pebbles up to 25 mm in diameter; abundant (up to 80 percent) euhedral quartz overgrowths(?); 0.5 to 1.0 percent dark opaque grains; some TiO_2 minerals; locally abundant hematitic staining; friable.	Composite of plus-6-inch (15-cm) stockpile.	Potential for a feldspathic yellow glass.	Chemically meets typical analyses for white glass.	Unusual heavy-mineral suite with abundant tourmaline, some rutile, brookite, and anatase, and rare zircon.
S-36-81 S-36B-81	do.	do.	Sandstone, white, medium-grained (0.5 mm and less); abundant clear euhedral quartz overgrowths (up to 80 percent); 0.5 to 1 percent dark opaque grains; some brookite and anatase; friable.	High-grade composite of medium-grained sandstone from stockpile.	do.	do.	Abundant euhedral silica overgrowths; friable.
S-37-81 S-37B-81	Sunfish Pond Leroy Township Bradford County SW 1/4 Leroy 7-1/2-minute quadrangle 41°38′39″N/76°41′44″W	do.	Sandstone, white to yellowish-gray, medium- to coarse-grained (0.25 to 2 mm), subrounded to subangular; minor euhedral quartz overgrowths; some "clay-mica" in matrix; locally abundant dark opaque grains; some carbonaceous debris; locally abundant limonitic and hematitic staining; outer leached(?) white zones common in outcrop.	Grab sample of float and outcrop around the east and south perimeter of pond.	—	Chemically Fe_2O_3 meets typical analyses for white glass.	See Smith and Berkheiser (1983) for discussion of leaching phenomenon.

Table 17. *(Continued)*

Sample numbers	Name and location	Geologic age Formation Attitude of bed or vein	Petrographic description	Sampled interval and type	Highest potential uses "as-collected"	Highest potential uses after "beneficiation"	Comments
S-38-81 S-38B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1 Greene and Guilford Townships Franklin County SE 1/4 Scotland 7-1/2-minute quadrangle 39°53′30″N/77°30′54″W	Cambrian Antietam	Sandstone and quartzite, white, medium- to coarse-grained (0.5 to 0.75 mm), subrounded; some white "clay-mica"; some rose quartz grains; rare dark opaque grains; *Skolithos* common; both friable sand and vitreous quartzite are locally present.	Composite of white sand stockpile.	Chemically, Fe_2O_3 meets typical white-glass analyses. Potential proppant.	Chemically meets typical white-glass analyses. Physical characteristics appear compatible.	Lowest "as collected" Fe_2O_3 value of any sample tested. Potential glass-sand target.
S-39-81 S-39B-81	do.	do.	Sandstone and quartzite, very pale orange, medium- to coarse-grained (0.5 to 0.75 mm), subrounded; some white "clay-mica"; limonitic staining common; some rose quartz grains; rare dark opaque grains; *Skolithos* common.	Composite of buff sand stockpile.	Potential for a feldspathic yellow glass. Proppant.	do.	Al_2O_3 and Fe_2O_3 values clean up better than the white sand. Potential glass-sand target.
S-41-82 S-41B-82	Lee Mountain outcrop Briar Creek Township Columbia County NW 1/4 Berwick 7-1/2-minute quadrangle 41°06′53″N/76°14′13″W	Mississippian Lower half Pocono N80°E, 33°NW	Sandstone and conglomerate, very light gray to light-brown, coarse-grained (0.75 to 1.0 mm); some pebbles up to 1 cm; subrounded to rounded; some "clay-mica" as matrix and clasts; limonitic and hematitic staining common; locally friable.	Composite of outcrop representing about 10 feet (3 m) of stratigraphic section.	Chemically near typical refractory-ganister analyses.	Chemically meets typical white-glass analyses.	Cleans up very well. Most "Fe_2O_3" must be in oxidized state. Effect of natural leaching?
S-46-82 S-46B-82	Valley Forge Stone Honeybrook Township Chester County N/E 1/4 Honey Brook 7-1/2-minute quadrangle 40°07′27″N/75°54′06″W	Cambrian Chickies N78°W, 40°NW	Quartzite and sandstone, very light gray to white; medium- to coarse-grained (average 0.75 mm but up to 4 mm in diameter); rounded to subrounded; abundant "clay-mica" along fracture surfaces and in matrix as grains; vitreous and breaks through grains; some pink rose quartz; rare dark opaque grains.	Composite of mason sand stockpile.	Chemically meets feldspathic yellow-glass analyses; however, induration and gradation are not compatible.	do.	Similar nearby abandoned quarry once produced silica for foundry operations, cupola and ladle linings, sand molds, carrier in fertilizer, and silica additive in blast furnaces (Harris and Millar, 1965).
S-48-82 S-48B-82	Abandoned quarry at Oyster Point West Hempfield Township Lancaster County Columbia East 7-1/2-minute quadrangle 40°03′32″N/76°24′28″W	Cambrian Chickies N15°E, 59°SE	Quartzite and sandstone, very light gray to white, some yellowish gray; matrix is fine to very fine grained (< 0.25 mm) and contains floating coarse grains (up to 1 mm); mostly vitreous; common tourmaline; some zircon and rutile; some limonitic and rarer hematitic staining; texture is micro breccia (tectonized).	Face composite, about 290-foot (90-m) sampled interval and about 245 feet (75 m) of stratigraphic section.	Chemically has potential as refractory ganister; close to typical analyses.	do.	No specific site development potential.

S-49-82 S-49B-82	Neumans quarry, York Stone and Supply Company, Inc. Springettsbury Township York County NW 1/4 York 7-1/2-minute quadrangle 39°59′46″N/76°43′12″W	Cambrian Chickies N40°E, 54°NW	Quartzite, very light gray to light-gray, some yellowish gray; medium grained (0.5 mm); vitreous; sucrosic texture; some limonite-after-pyrite cubes; some hematitic staining; some "clay-mica" as fracture coatings; possible tourmaline, and carbonaceous fragments and coatings; minor quartz veins (< 1 cm thick).	Composite of face and muck pile, northernmost quarry, lowest lift.	—	Chemically near typical yellow-glass analyses; however, gradation and induration are not compatible.	—
S-51-82 S-51B-82	Martinsburg, Tussey Mountain roadcut Liberty Township Bedford County SE 1/4 Martinsburg 7-1/2-minute quadrangle 40°17′47″N/78°15′31″W	Silurian Tuscarora N20°E, 45°SE	Sandstone and quartzite, white to very light gray, some yellowish gray; medium to coarse grained (0.25 to 0.5 mm); rounded to subangular; locally vitreous; white "clay-mica" and schorl tourmaline common along some bedding planes; zircon(?); rare light-green mica; minor limonitic staining.	Roadcut composite representing about 105 feet (32 m) of stratigraphic section overlying about 42 feet (13 m) of transitional pink lithofacies.	Chemically meets typical analyses for feldspathic yellow glass; however, induration and gradation are not compatible.	Chemically meets typical white-glass analyses; however, induration and gradation are not compatible.	Cotter's (1982, 1983), basal horizontally laminated beach lithofacies is the best ganister source. Some 10-cm- (4-in-) thick clay beds in roadcut.
S-52-82 S-52B-82	Waggoners Gap roadcut Lower Frankford Township Cumberland County SE 1/4 Landisburg 7-1/2-minute quadrangle 40°16′36″N/77°16′27″W	Silurian Tuscarora N77°E, 59°NW	Sandstone and quartzite, light-gray to white, some yellowish gray; medium grained (0.25 to 0.5 m); rounded to subrounded; locally vitreous; some white "clay-mica" as grains and coatings; some limonitic staining; tourmaline and other "heavies" along some bedding planes; some wavellite locally present; minor small milky quartz veins locally.	Roadcut composite representing basal 55-foot (17-m) stratigraphic section overlain by an additional 36 feet (11 m) of wavellite and hematite-rich beach lithofacies.	do.	do.	Phosphate minerals are locally common near upper part of section. Abundant mineralization not sampled (Smith, 1978).
S-54-82 S-54B-82	Harbison-Walker Refractories Mt. Union quarry and plant Shirley Township Huntingdon County SE 1/4 Mt. Union 7-1/2-minute quadrangle 40°22′54″N/77°54′12″W	Silurian Tuscarora N10°E, 34°SW	Sandstone and quartzite, very light gray, some yellowish gray and greenish gray; coarse grained (0.5 to 1.0 mm), containing some 2-mm grains; locally vitreous; hematitic and limonitic staining common; white "clay-mica" as grains and coatings; jarosite locally common; local occurrences of sphalerite, chalcopyrite, pyrite, and galena as minute blebs in light-gray quartzite.	Composite of production stockpile. Quarry is located on south side of river, east flank of Jacks Mountain, at elevation of approximately 1,350 feet (410 m).	Used as a refractory ganister.	do.	Active silica refractories operation. Quarry is not developed in Cotter's (1982, 1983) basal horizontally laminated beach lithofacies.
S-56-82 S-56B-82 S-56BB-82	Pennsylvania Glass Sand Corporation, Keystone Works Brady Township Huntingdon County SE 1/4 Mount Union 7-1/2-minute quadrangle 40°26′23″N/77°54′47″W	Devonian Old Port, Ridgeley Member ("Oriskany")	Sandstone and quartzite, very light gray to white, medium- to coarse-grained (0.25 to 1.0 mm), rounded to subangular, locally vitreous; some staining; some "clay-mica" as grains; rare wavellite and cacoxenite in small vugs; rare tourmaline; some shell casts.	Composite of diamond-drill-hole core, approximately 140 feet (43 m) of stratigraphic section from the Hawn pit.	Chemically close to typical yellow-sand analyses. Potential for proppant.	Chemically meets typical white-glass analyses.	Does not represent total thickness of Ridgeley section. About 40 feet (12 m) of basal sandstone not reported.

Table 17. (Continued)

Sample numbers	Name and location	Geologic age Formation Attitude of bed or vein	Petrographic description	Sampled interval and type	Highest potential uses "as-collected"	Highest potential uses after "beneficiation"	Comments
S-61-82 S-61B-82 S-61BB-82	Firetower, Tuscarora Mountain outcrop Metal Township Franklin County NE 1/4 McConnellsburg 7-1/2-minute quadrangle 39°57′02″N/77°56′13″W	Silurian Tuscarora N35°E, 15°NW	Sandstone and quartzite, white to very light gray, coarse-grained (0.5 to 1 mm), rounded to subrounded; rare "clay mica" as grains and coatings; rare tourmaline; anatase(?); locally vitreous minor coarser grained zones (1 mm) containing common "clay-mica"; minor thin pure vitreous zones.	Composite outcrop; represents about 50 feet (15 m) of stratigraphic section.	Chemically, Fe_2O_3 meets typical white-glass analyses. Induration not compatible.	Chemically meets typical white-glass analyses. Induration not compatible.	Beneficiated Fe_2O_3 is very low. Cotter's (1982, 1983) basal horizontally laminated beach lithofacies.
S-64-82 S-64B-82	Cornog quartz vein Private property Wallace Township Chester County NE 1/4 Wagontown 7-1/2-minute quadrangle 40°04′45″N/75°45′09″W	Cambrian(?) Near vertical(?)	Quartz vein, very light gray; milky quartz; some limonitic and hematitic staining locally common; minor specular hematite; minor mica.	Composite of flint dump; purer than composite of face. Abandoned workings are 40 feet (12 m) wide, 30 feet (9 m) on the face, and 100 feet (30 m) long.	Chemically meets typical analyses for silicon production.	Chemically very close to typical[1] lasca analyses.	Best beneficiated values tested. Previously mined for sandpaper and steel flux (Stone, 1939).
S-65-83 S-65B-83 S-65BB-83	Weaver Gap, abandoned Rife Brothers dimension stone quarry Hamilton Township Franklin County SE 1/4 Fannettsburg 7-1/2-minute quadrangle 40°00′17″N/77°47′22″W	Silurian Tuscarora N33°E, 14°SE	Sandstone and minor quartzite, very light gray to white, medium-grained (0.25 to 0.5 mm); breaks mostly around grain boundaries; rare "clay-mica" grains; rounded to subrounded; rare tourmaline and pink rose quartz grains; ripple marks in outcrop.	Composite face sample, north face; approximately 25 feet (8 m) of exposed stratigraphic section.	Potential for feldspathic glass sand. Proppant(?).	Chemically meets typical white-glass analyses. Induration questionable.	Cotter's (1982, 1983) basal horizontally laminated beach lithofacies. Appears to break around individual grains.

[1] Samples that meet typical lasca analyses also meet typical chemical analyses for white glass, refractory pebble, silicon production, metallurgical quartz, yellow glass, and refractory ganister. Samples that meet typical white-glass analyses also meet typical chemical analyses for refractory pebble, silicon production, metallurgical quartz, yellow glass, and refractory ganister.

Table 18. *County Listing of Samples Analyzed*

County	Sample number	Locality name	Geologic age Formation
Adams	S-26-81 S-26B-81	Abandoned Summit Mining Company pit	Precambrian(?) Quartz vein
do.	S-27-81 S-27B-81 S-27BB-81	Abandoned Moses Black quartz vein	do.
Bedford	S-51-82 S-51B-82	Martinsburg, Tussey Mountain	Silurian Tuscarora
Berks	S-1-81 S-1B-81	Berks Silica Sand quarry	Cambrian Hardyston
Bradford	S-37-81 S-37B-81	Sunfish Pond	Pennsylvanian Lower Pottsville Group
Chester	S-46-81 S-46B-81	Valley Forge Stone	Cambrian Chickies
do.	S-64-82 S-64B-82	Cornog quartz vein	Cambrian(?) Quartz vein
Columbia	S-41-82 S-41B-82	Lee Mountain	Mississippian Pocono
Cumberland	S-20-81 S-20B-81 S-20BB-81	Benders quarry, Mount Holly Springs	Cambrian Antietam
do.	S-21-81 S-21B-81	Hempt Brothers, Toland	Cambrian Harpers, Montalto Member
do.	S-22-81 S-22B-81	do.	do.
do.	S-23-81 S-23B-81 S-23BB-81	State borrow pit, Pine Grove Furnace	do.
do.	S-30-81 S-30B-81	Dead Woman Hollow quartz vein	Precambrian(?) Quartz vein
do.	S-52-81 S-52B-81	Waggoners Gap	Silurian Tuscarora
Franklin	S-28-81 S-28B-81	Abandoned Caledonia North quartz vein	Precambrian(?) Quartz vein
do.	S-29-81 S-29B-81	Abandoned Caledonia South quartz veins	do.
do.	S-38-81 S-38B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Cambrian Antietam
do.	S-39-81 S-39B-81	do.	do.
do.	S-61-82 S-61B-82 S-61BB-82	Firetower, Tuscarora Mountain	Silurian Tuscarora
do.	S-65-83 S-65B-83 S-65BB-83	Weaver Gap, Rife Brothers quarry	do.
Huntingdon	S-54-81 S-54B-81	Harbison-Walker, Mount Union quarry	do.
do.	S-56-82 S-56B-82 S-56BB-82	Pennsylvania Glass Sand, Keystone Works	Devonian Old Port, Ridgeley Member

Table 18. *(Continued)*

County	Sample number	Locality name	Geologic age Formation
Lancaster	S-48-82 S-48B-82	Oyster Point	Cambrian Chickies
Monroe	S-17-81 S-17B-81	Eastern Industries, Kunkletown	Devonian Palmerton
Schuylkill	S-6-81 S-6B-81 S-6BB-81	Huss Contracting Company and Refractory Sand Company	do.
do.	S-8-81 S-8B-81	do.	do.
Tioga	S-32-81 S-32B-81	Warwick Sand Company	Pennsylvanian Lower Pottsville Group
do.	S-35-81 S-35B-81	High Mountain quarry	do.
do.	S-36-81 S-36B-81	do.	do.
York	S-49-81 S-49B-81	Neumans quarry	Cambrian Chickies

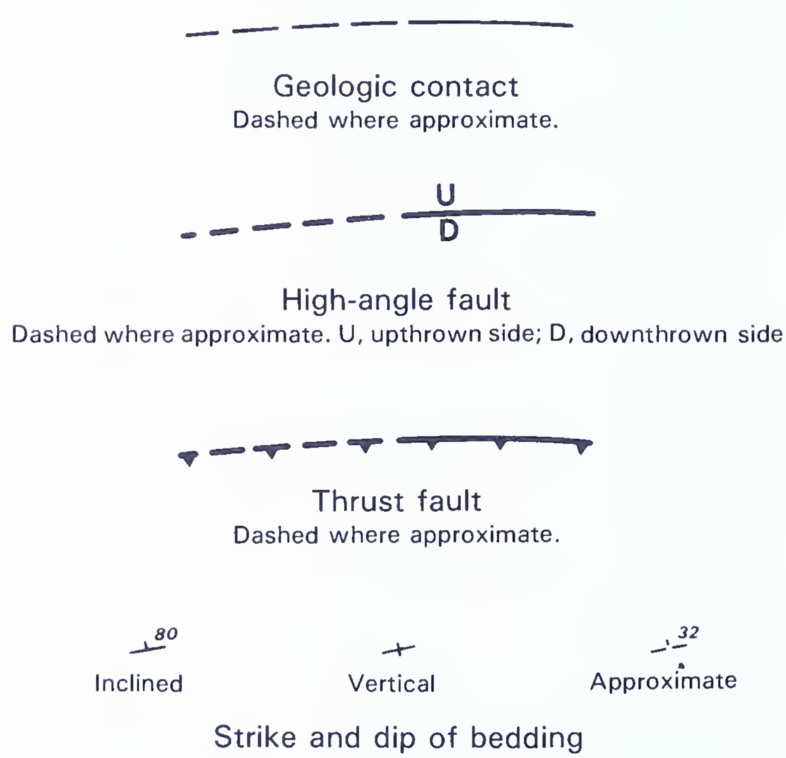
Table 19. *Formational Listing of Samples Analyzed*

Geologic age Formation	Sample number	Locality name	County
Pennsylvanian Lower Pottsville Group	S-32-81 S-32B-81	Warwick Sand Company	Tioga
do.	S-35-81 S-35B-81	High Mountain quarry	do.
do.	S-36-81 S-36B-81	do.	do.
do.	S-37-81 S-37B-81	Sunfish Pond	Bradford
Mississippian Pocono	S-41-81 S-41B-81	Lee Mountain	Columbia
Devonian Palmerton	S-6-81 S-6B-81 S-6BB-81	Huss Contracting Company and Refractory Sand Company	Schuylkill
do.	S-8-81 S-8B-81	do.	do.
do.	S-17-81 S-17B-81	Eastern Industries, Kunkletown	Monroe
Devonian Old Port, Ridgeley Member ("Oriskany")	S-56-82 S-56B-82 S-56BB-82	Pennsylvania Glass Sand, Keystone Works	Huntingdon
Silurian Tuscarora	S-51-82 S-51B-82	Martinsburg, Tussey Mountain	Bedford
do.	S-52-82 S-52B-82	Waggoners Gap	Cumberland
do.	S-54-82 S-54B-82	Harbison-Walker, Mount Union quarry	Huntingdon

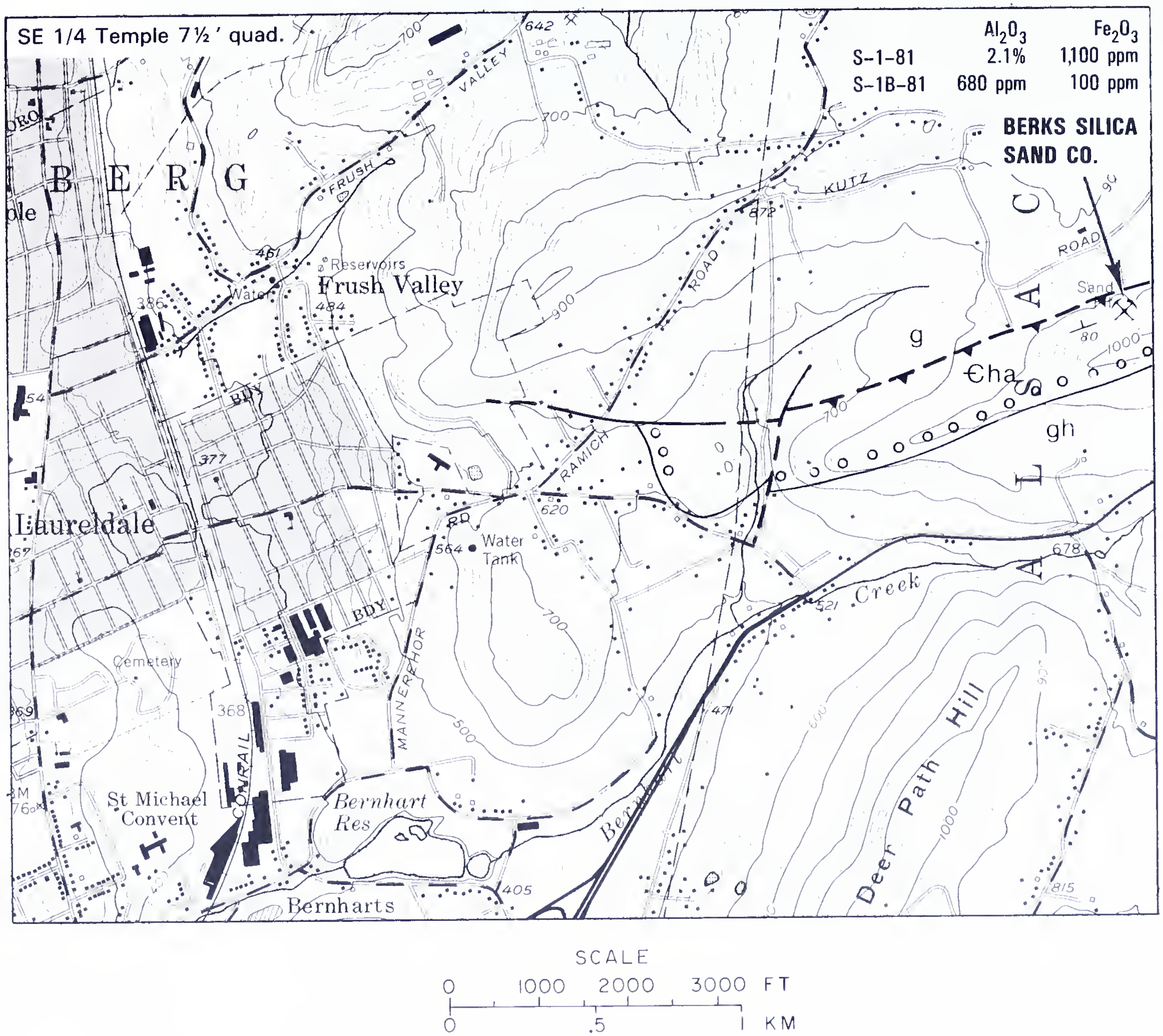
Table 19. *(Continued)*

Geologic age Formation	Sample number	Locality name	County
Tuscarora	S-61-82 S-61B-82	Firetower, Tuscarora Mountain	Franklin
do.	S-65-83 S-65B-83 S-65BB-83	Weaver Gap, Rife Brothers quarry	do.
Cambrian Antietam	S-20-81 S-20B-81 S-20BB-81	Benders quarry, Mount Holly Springs	Cumberland
do.	S-38-81 S-38B-81	Mount Cydonia Sand and Gravel Company, Plant No. 1	Franklin
do.	S-39-81 S-39B-81	do.	do.
Cambrian Harpers, Montalto Member	S-21-81 S-21B-81	Hempt Brothers, Toland	Cumberland
do.	S-22-81 S-22B-81	do.	do.
do.	S-23-81 S-23B-81 S-23BB-81	State borrow pit, Pine Grove Furnace	do.
Cambrian Chickies	S-46-82 S-46B-82	Valley Forge Stone	Chester
do.	S-48-82 S-48B-82	Oyster Point	Lancaster
do.	S-49-82 S-49B-82	Neumans quarry	York
Cambrian Hardyston	S-1-81 S-1B-81	Berks Silica Sand quarry	Berks
Cambrian(?) Quartz vein	S-64-82 S-64B-82	Cornog quartz vein	Chester
Precambrian(?) Quartz vein	S-26-81 S-26B-81	Abandoned Summit Mining Company pit	Adams
do.	S-27-81 S-27B-81 S-27BB-81	Abandoned Moses Black quartz vein	do.
do.	S-28-81 S-28B-81	Abandoned Caledonia North quartz vein	Franklin
do.	S-29-81 S-29B-81	Abandoned Caledonia South quartz veins	do.
do.	S-30-81 S-30B-81	Dead Woman Hollow quartz vein	Cumberland

SYMBOLS USED ON FIGURES 12 THROUGH 33



NOTE: In Figures 12 through 33, the geologic units are shown only in the immediate vicinity of the silica localities. Other geologic units may be present within the boundaries indicated on the location maps but are not shown. Readers interested in the geology beyond the vicinity of the silica localities should consult the reference cited in the figure caption.



EXPLANATION

Єha

Hardyston Formation

Circle pattern indicates basal quartz-pebble conglomerate.

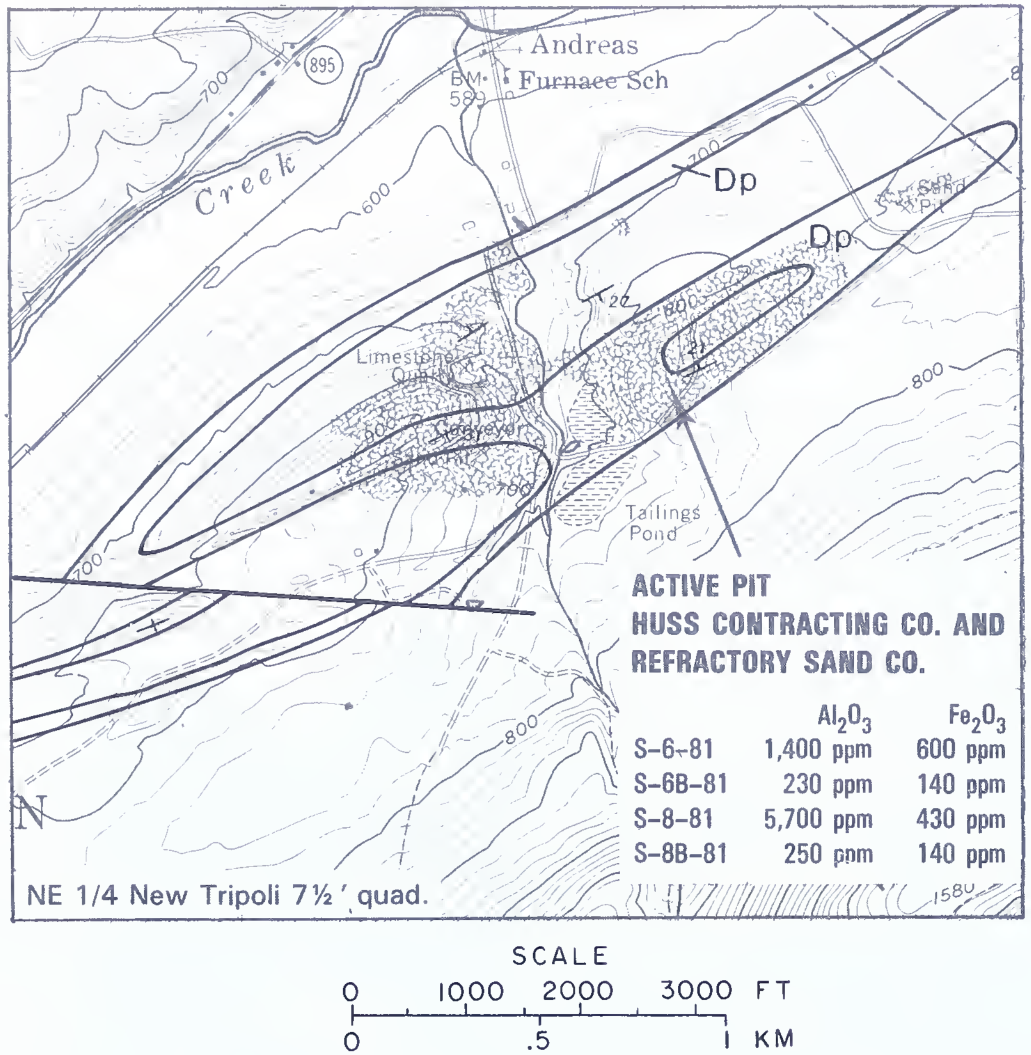
g

Granitic gneiss

gh

Granitic gneiss containing 20 to 30 percent hornblende gneiss

Figure 12. Geologic map showing the location of Berks Silica Sand Company quarry, Alsace Township, Berks County, samples S-1-81 and S-1B-81. Geology from MacLachlan (1979).

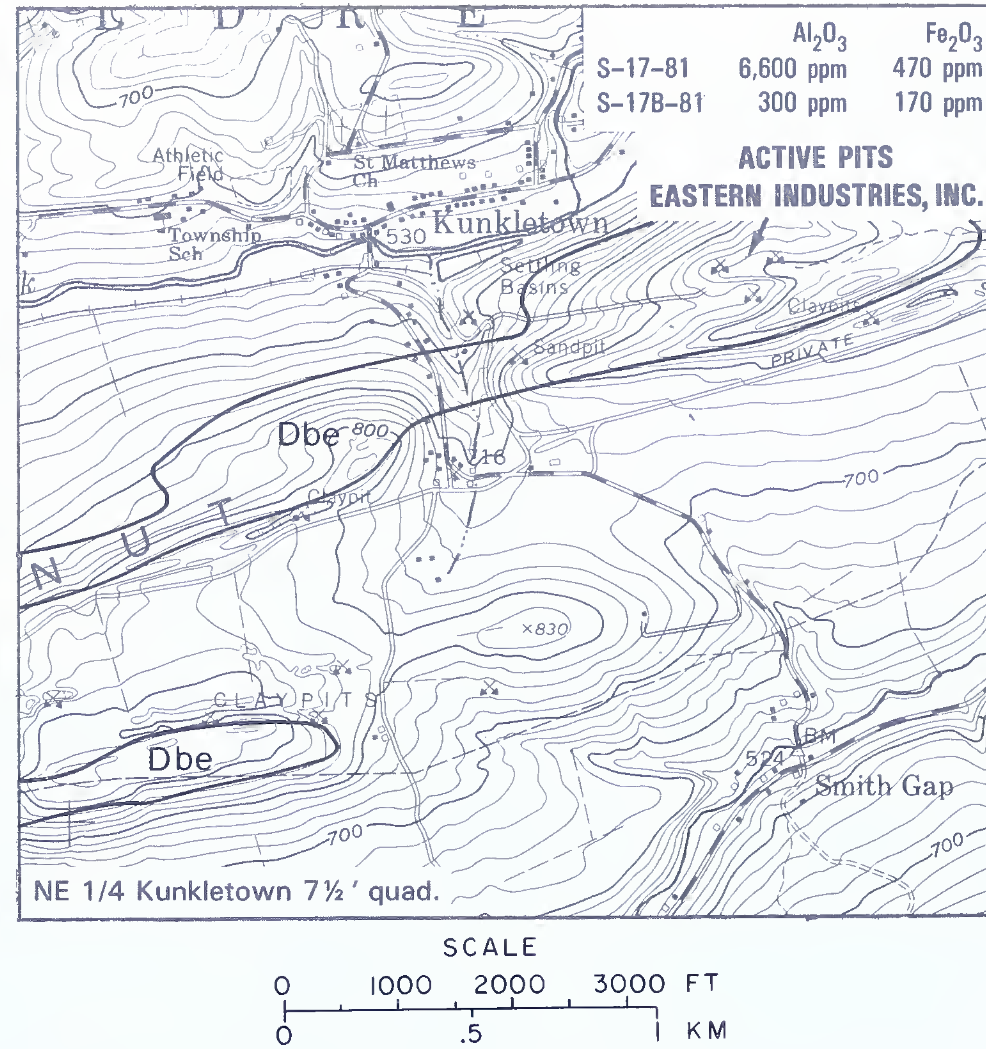


EXPLANATION

Dp

Palmerton Sandstone

Figure 13. Geologic map showing the location of Huss Contracting Company and Refractory Sand Company quarry, West Penn Township, Schuylkill County, samples S–6–81, S–6B–81, S–6BB–81, S–8–81, and S–8B–81. Geology from Sevon (1970).

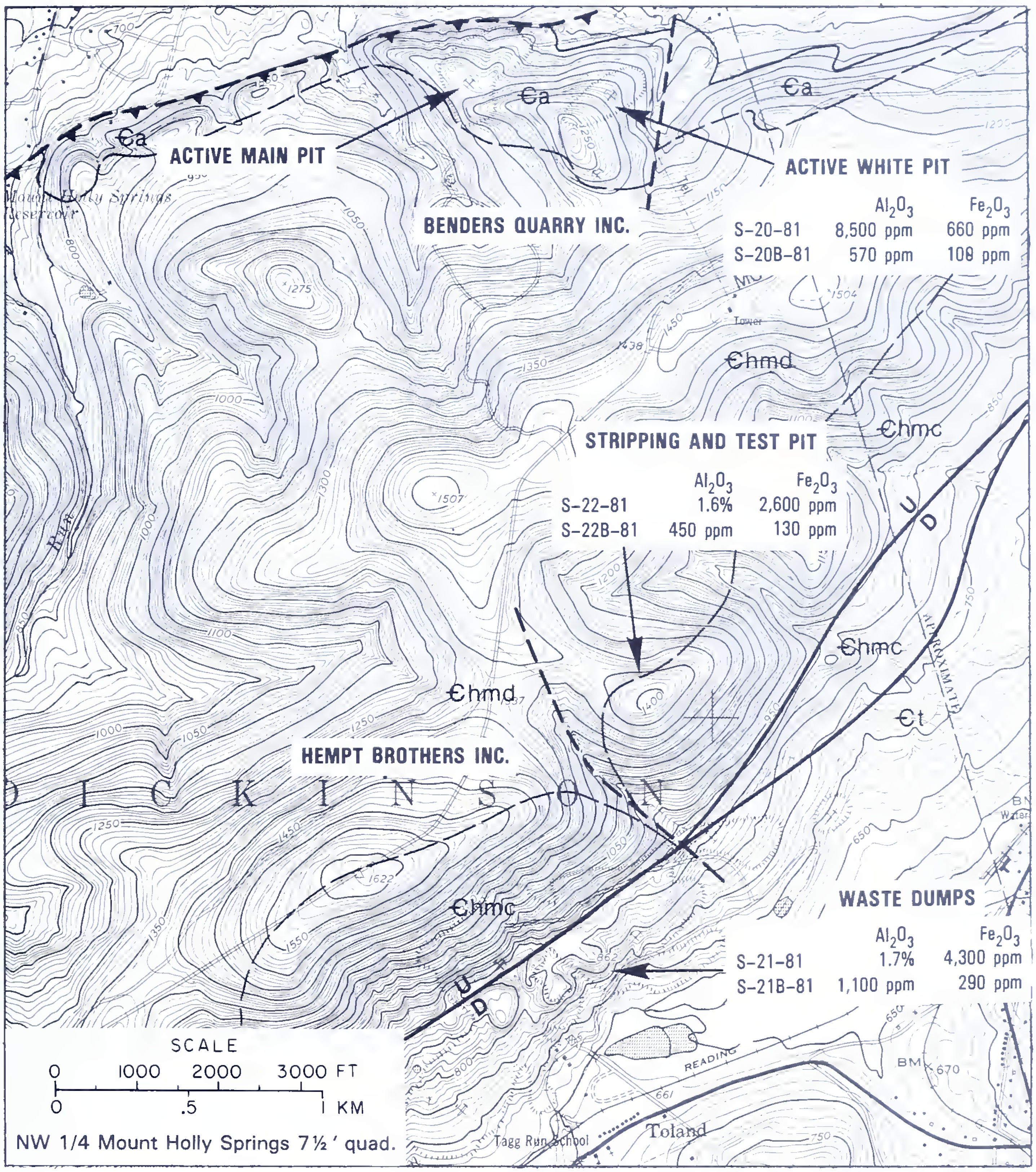


EXPLANATION

Dbe

Buttermilk Falls Limestone through Esopus Formation, undivided (includes Palmerton Sandstone)

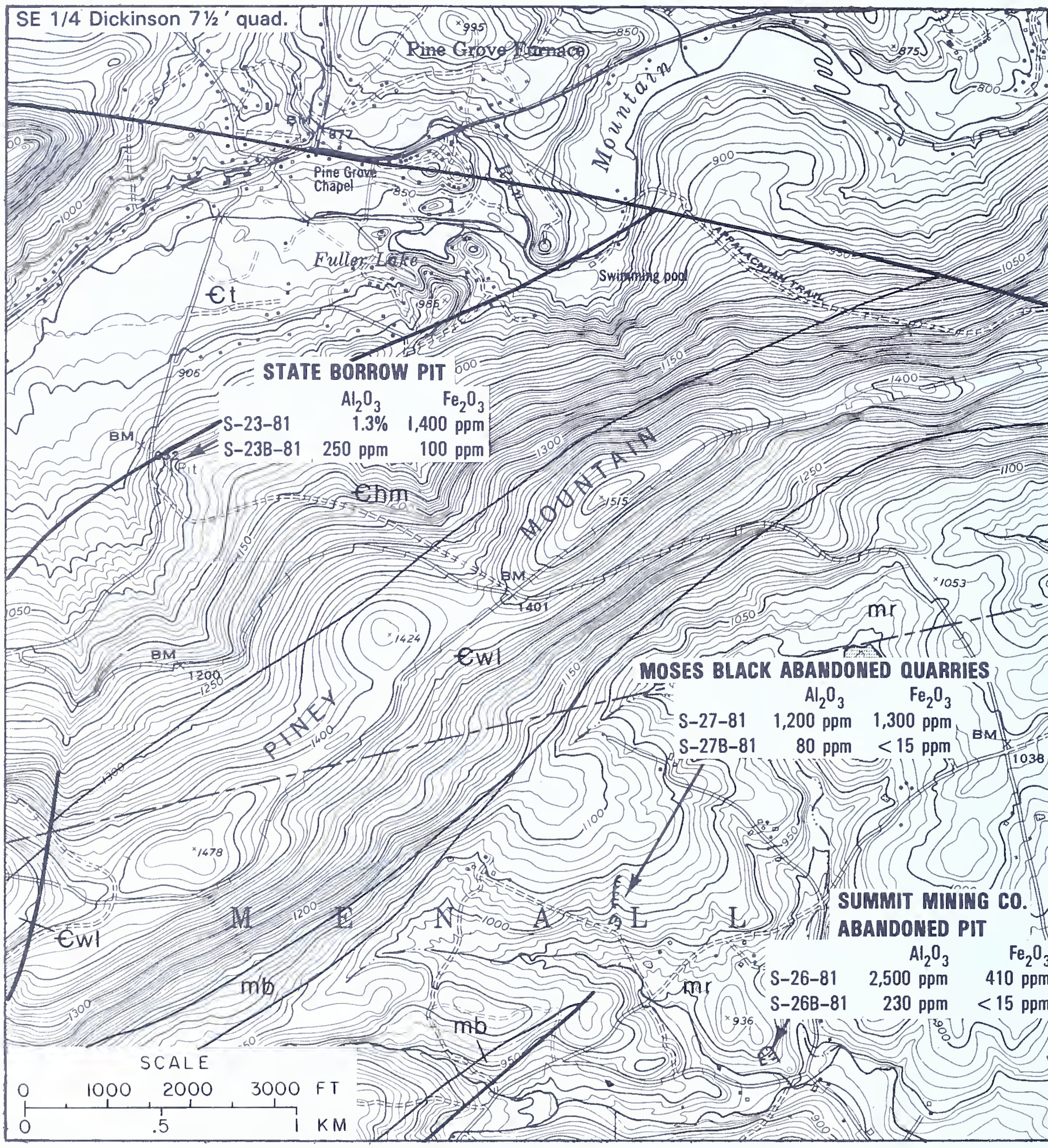
Figure 14. Geologic map showing the location of Eastern Industries, Kunkletown quarries, Eldred Township, Monroe County, samples S–17–81 and S–17B–81. Geology from Berg and Dodge (1981).



EXPLANATION

Ꞓt	Ꞓa	Ꞓhmd	Ꞓhmc
Tomstown Formation	Antietam Formation	Harpers Formation, Montalto Member, foliated quartzite	Harpers Formation, Montalto Member, vitreous quartzite

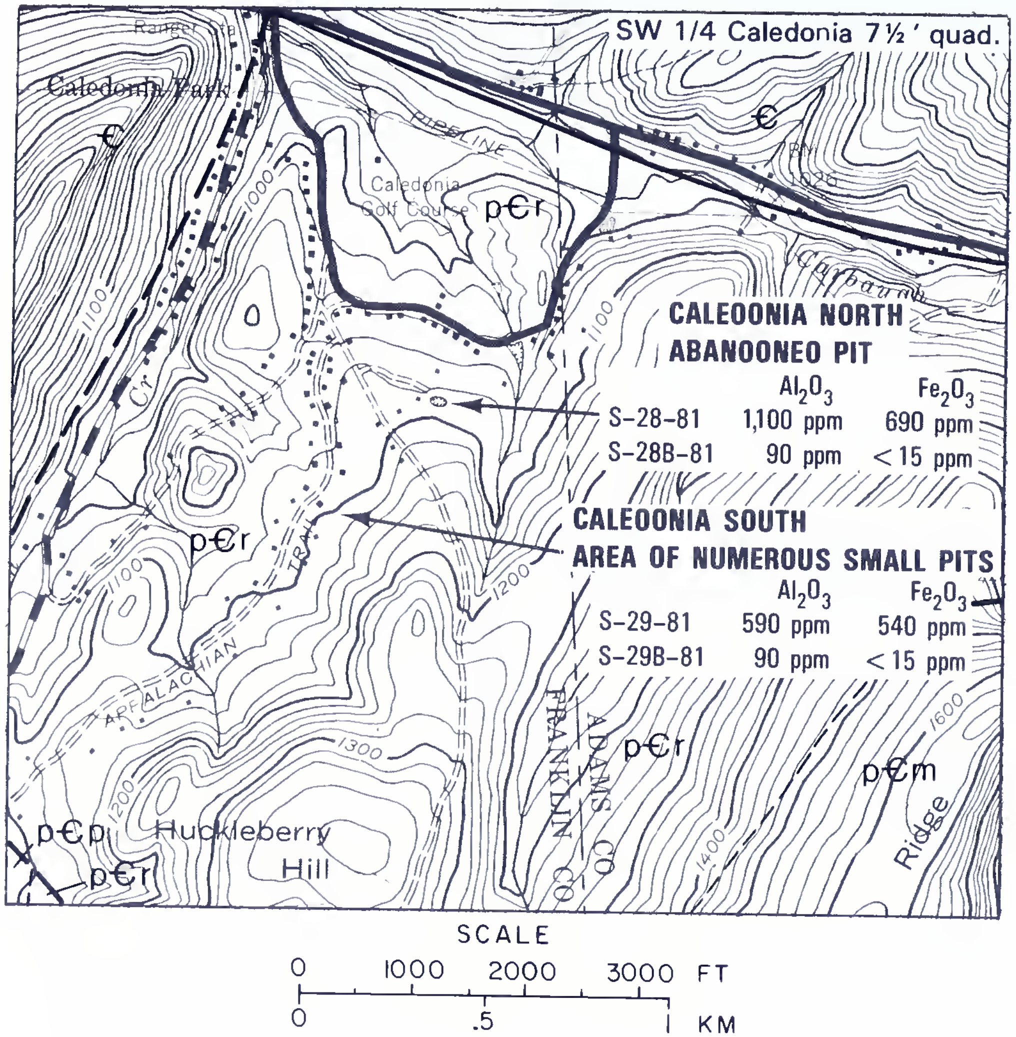
Figure 15. Geologic map showing the location of Benders Quarry, Inc., samples S-20-81, S-20B-81, and S-20BB-81; and Hempt Brothers Inc., Toland, samples S-21-81, S-21B-81, S-22-81, and S-22B-81, Dickinson Township, Cumberland County. Geology from Freedman (1967).



EXPLANATION

Ꞓt Tomstown Formation	Ꞓwl Weverton and Loudoun Formations, undivided	mr Metarhyolite
Ꞓhm Harpers Formation, Montalto Member	mb Metabasalt	

Figure 16. Geologic map showing the location of State borrow pit, Cooke Township, Cumberland County, samples S–23–81, S–23B–81, and S–23BB–81; abandoned Summit Mining Company pit, samples S–26–81 and S–26B–81; and abandoned Moses Black quartz vein, samples S–27–81, S–27B–81, and S–27BB–81, Menallen Township, Adams County. Geology from Berg and Dodge (1981).



EXPLANATION

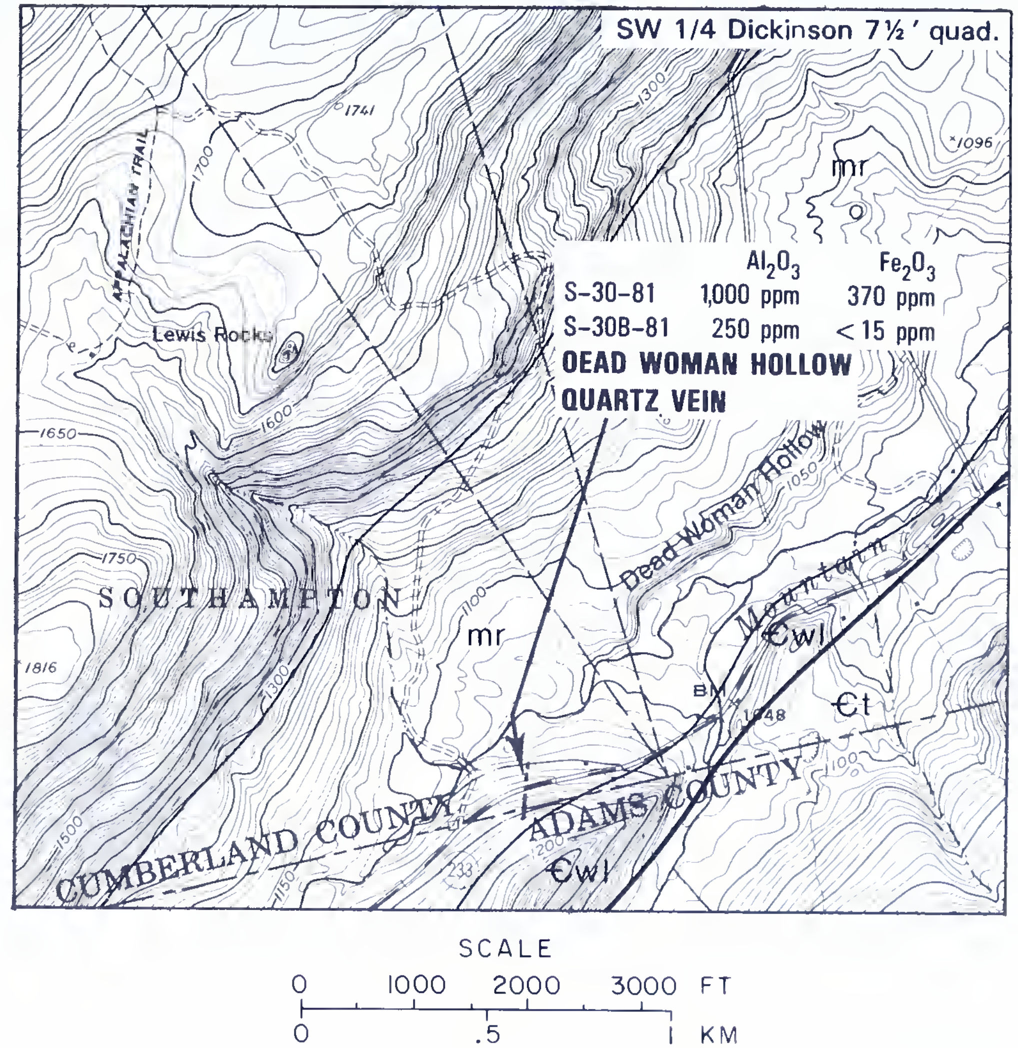
€
Cambrian sediments, undivided

p€m
Mottled metarhyolite unit

p€r
Blue metarhyolite unit

p€p
Phyllite

Figure 17. Geologic map showing the location of abandoned Caledonia North and South quartz veins, Green Township, Franklin County, samples S-28-81, S-28B-81, S-29-81, and S-29B-81. Geology from Fauth (1968).



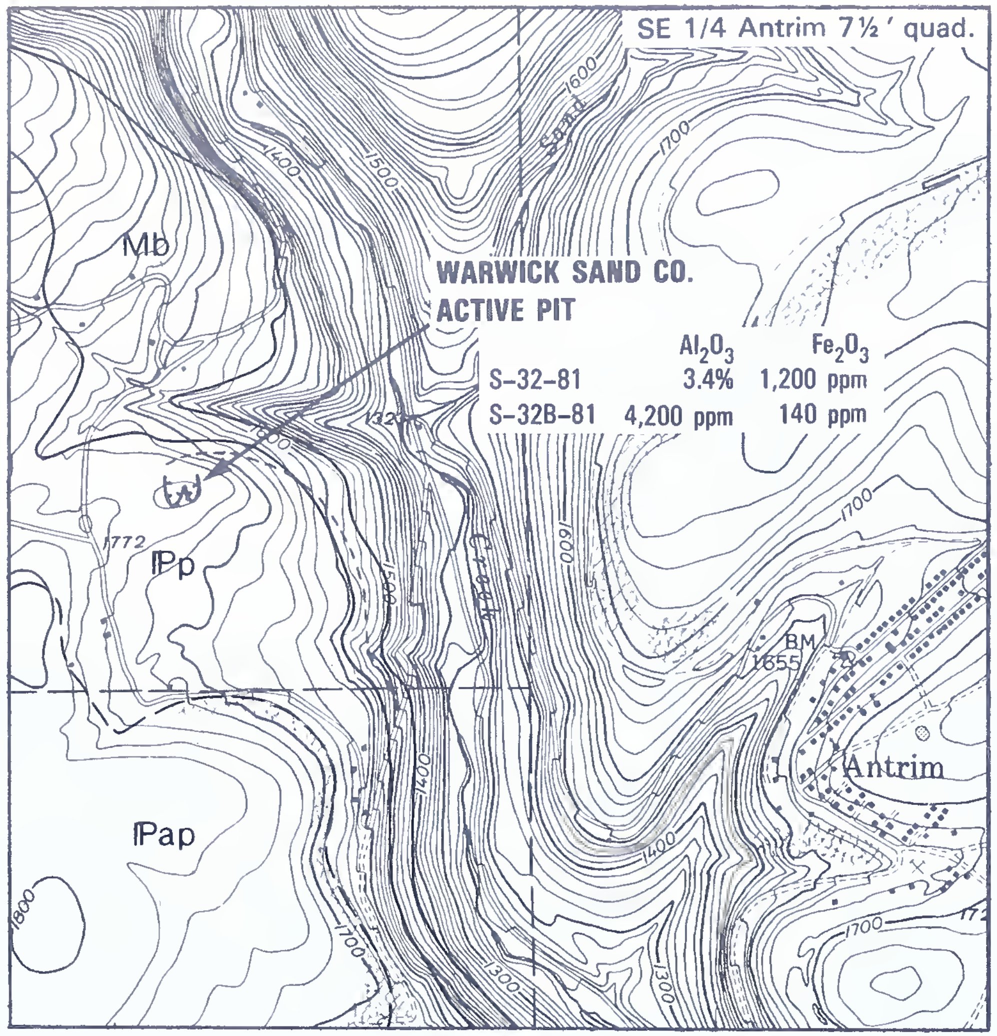
EXPLANATION

€t
Tomstown Formation

€wl
Weverton and Loudoun Formations, undivided

mr
Metarhyolite

Figure 18. Geologic map showing the location of Dead Woman Hollow quartz vein, Southampton Township, Cumberland County, samples S-30-81 and S-30B-81. Geology from Berg and Dodge (1981).



SCALE

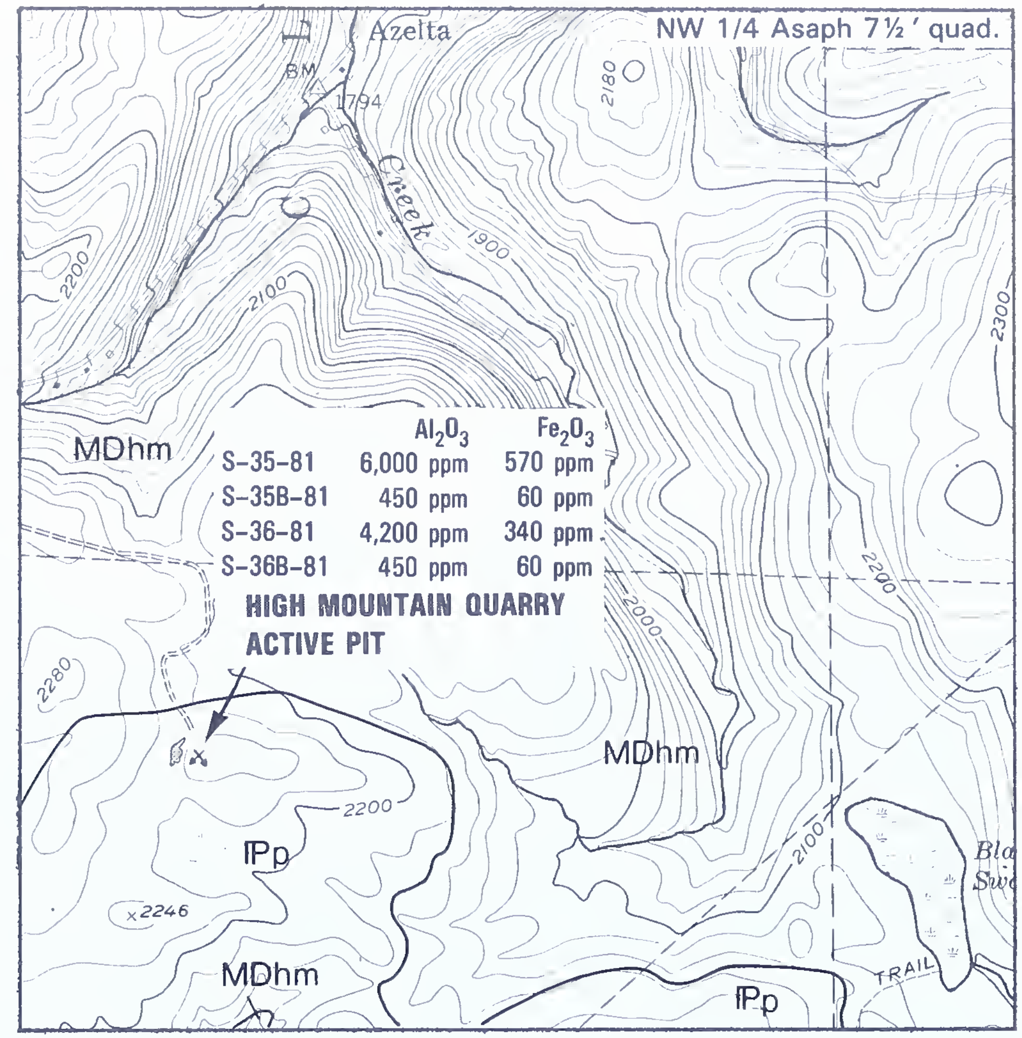
0 1000 2000 3000 FT

0 .5 1 KM

EXPLANATION

IPap	IPp	Mb
Allegheny and Pottsville Groups, undivided	Pottsville Group	Burgoon Sandstone

Figure 19. Geologic map showing the location of Warwick Sand Company active pit, Delmar Township, Tioga County, samples S-32-81 and S-32B-81. Geology from Berg and Dodge (1981).



SCALE

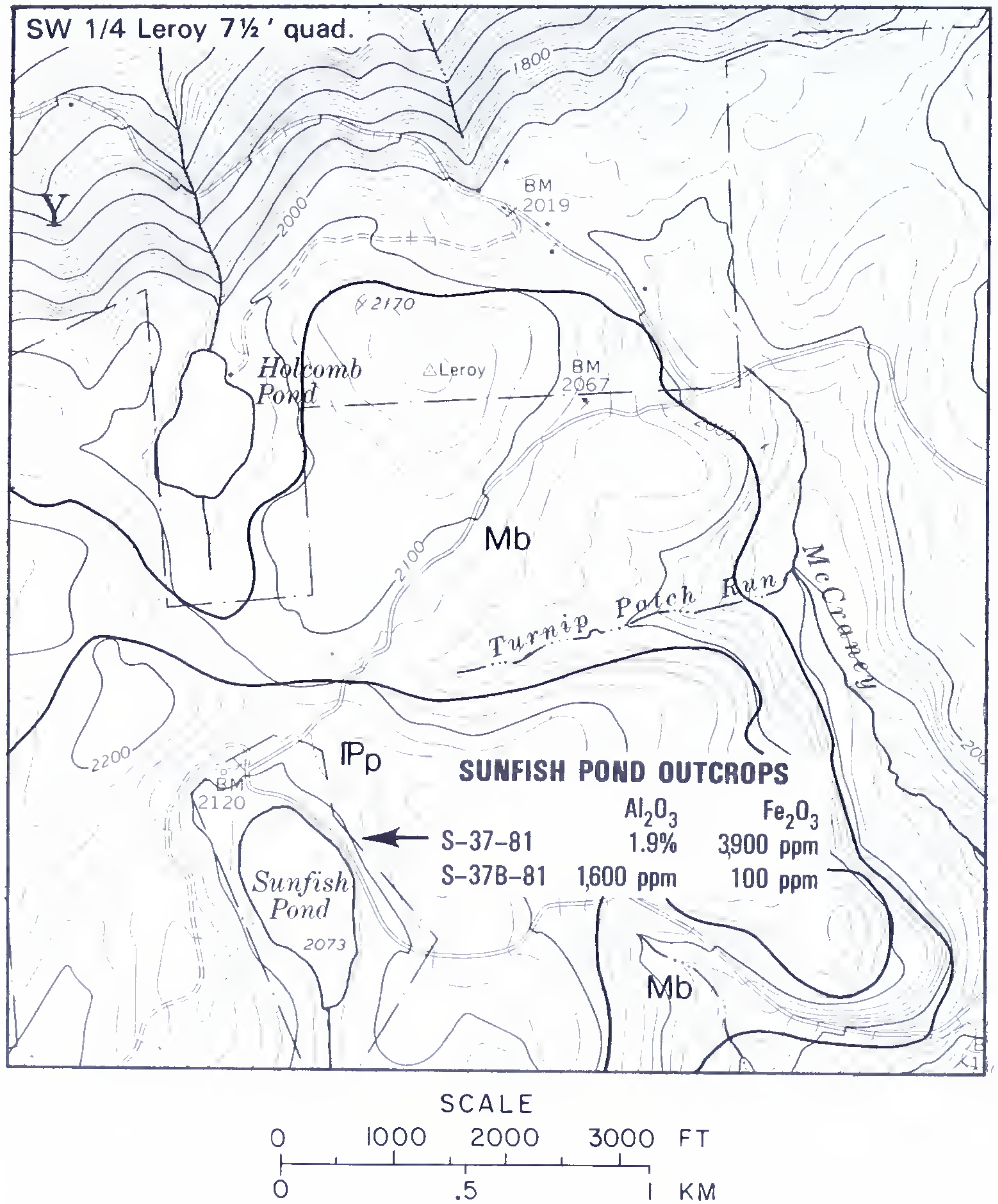
0 1000 2000 3000 FT

0 .5 1 KM

EXPLANATION

IPp	MDhm
Pottsville Group	Huntley Mountain Formation

Figure 20. Geologic map showing the location of High Mountain quarry, Clymer Township, Tioga County, samples S-35-81, S-35B-81, S-36-81, and S-36B-81. Geology from Berg and Dodge (1981).

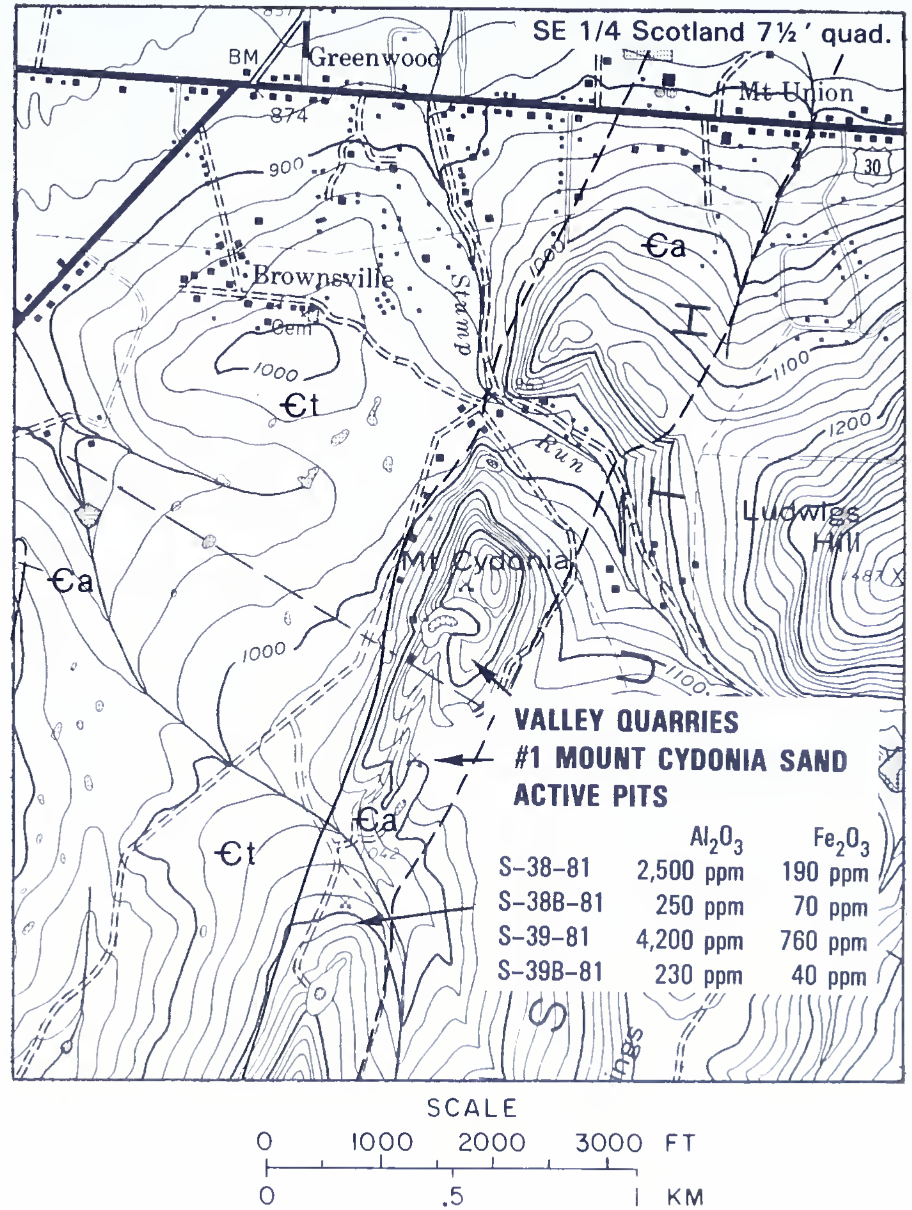


EXPLANATION

IPp Pottsville Group

Mb Burgoon Sandstone

Figure 21. Geologic map showing the location of Sunfish Pond outcrops, Leroy Township, Bradford County, samples S-37-81 and S-37B-81. Geology from Berg and Dodge (1981).

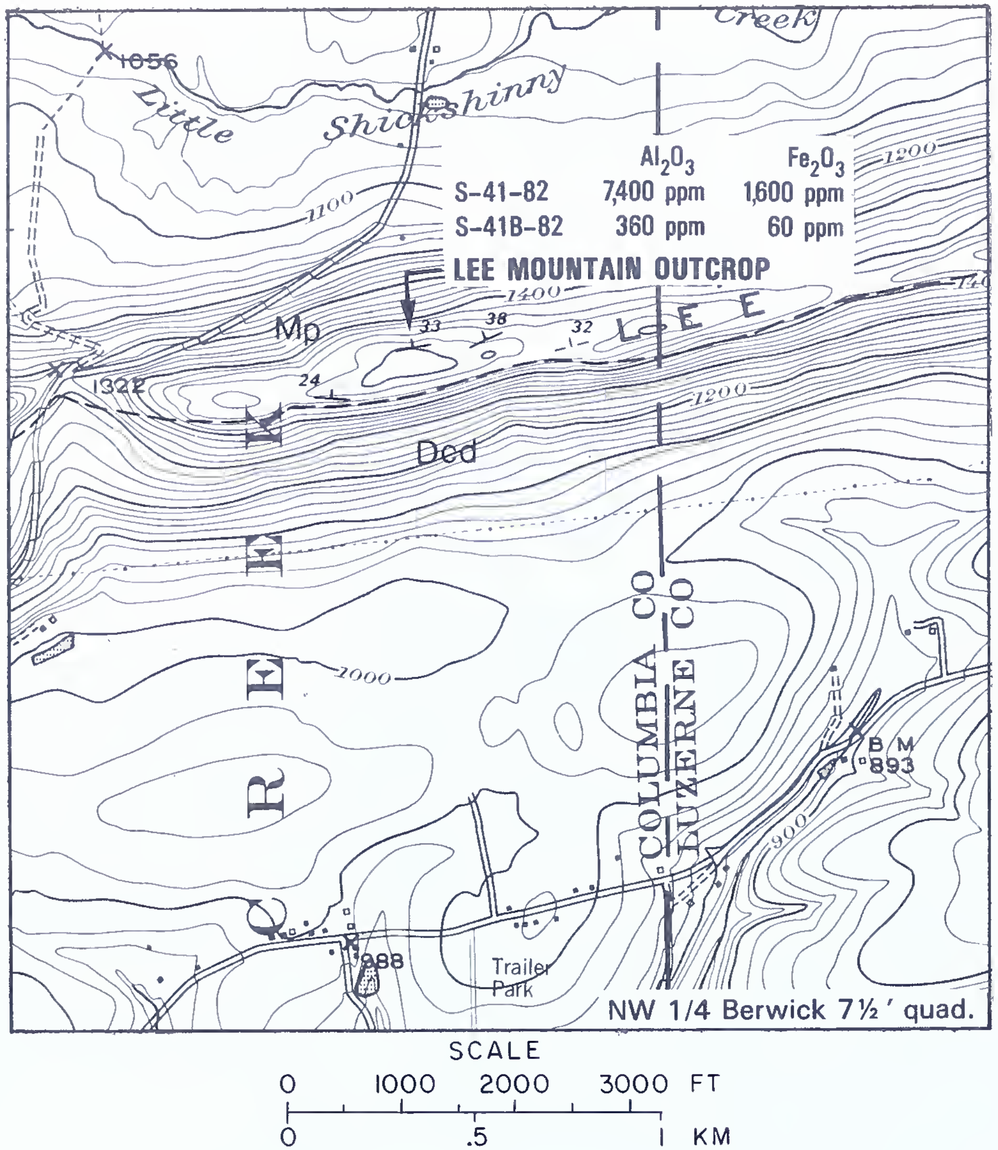


EXPLANATION

€t Tomstown Formation

€a Antietam Formation

Figure 22. Geologic map showing the location of Mount Cydonia Sand and Gravel Company, Plant No. 1, Green and Guilford Townships, Franklin County, samples S-38-81, S-38B-81, S-39-81, and S-39B-81. Geology from Fauth (1968).

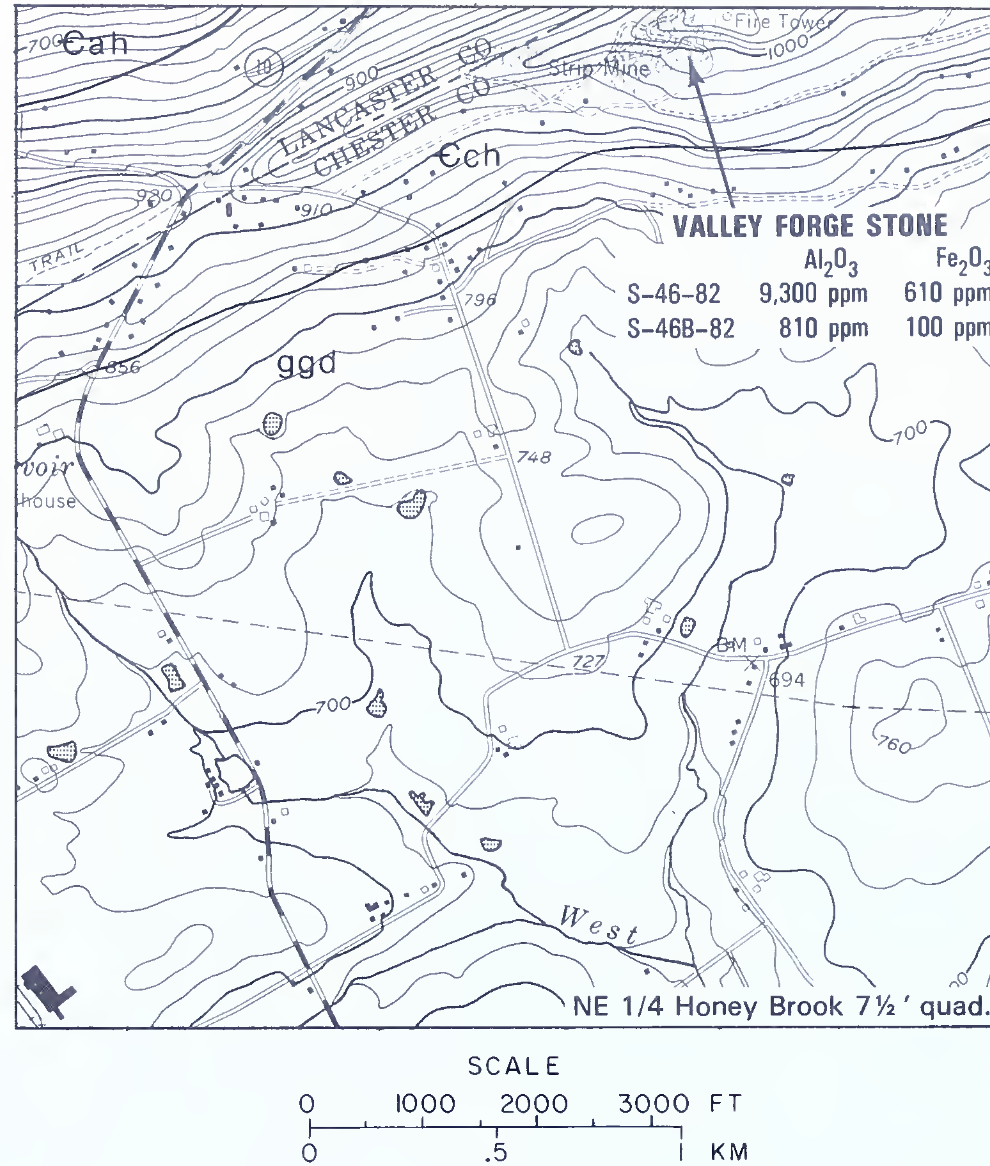


EXPLANATION

Mp — Pocono Formation

Dcd — Catskill Formation, Duncannon Member

Figure 23. Geologic map showing the location of Lee Mountain outcrop, Briar Creek Township, Columbia County, samples S-41-82 and S-41B-82. Geology from Inners (1978).



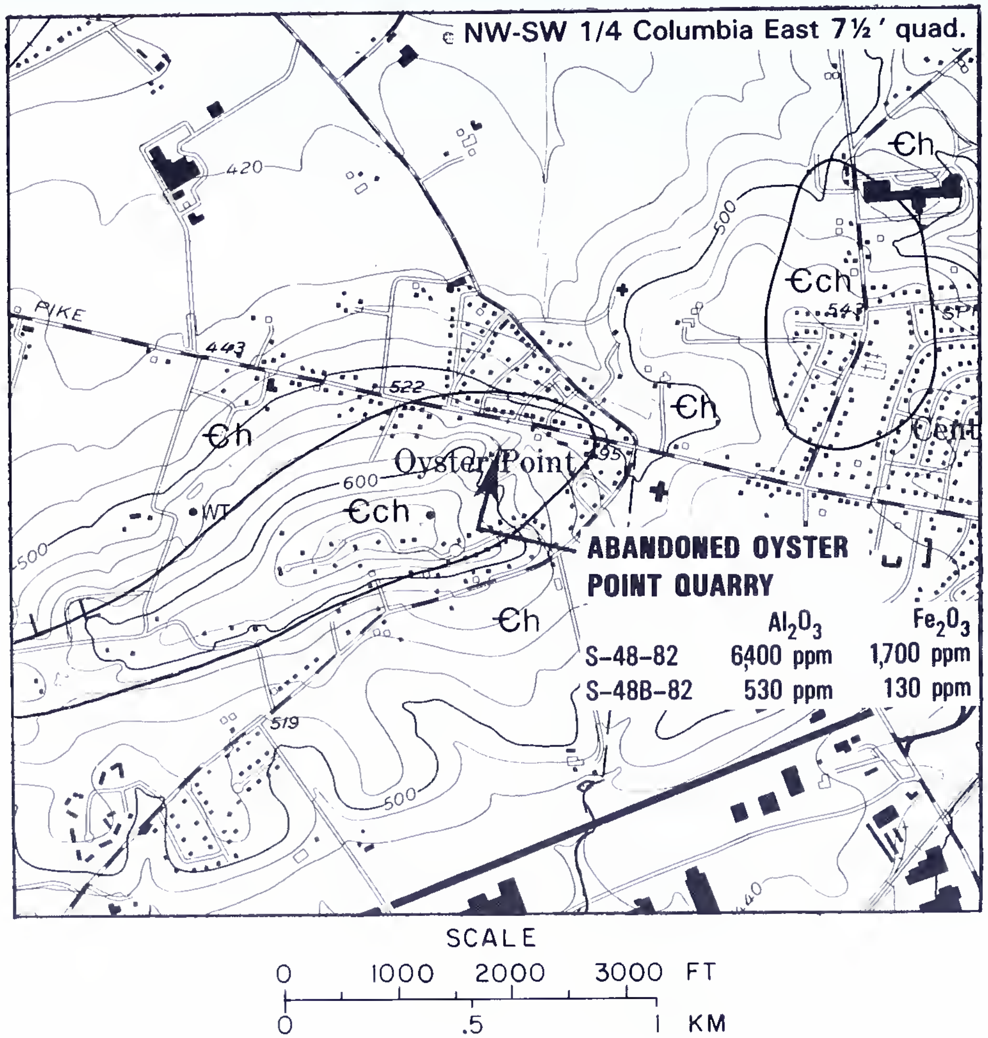
EXPLANATION

Ꞓah — Antietam and Harpers Formations, undivided

Ꞓch — Chickies Formation

ggd — Granodiorite and granodiorite gneiss

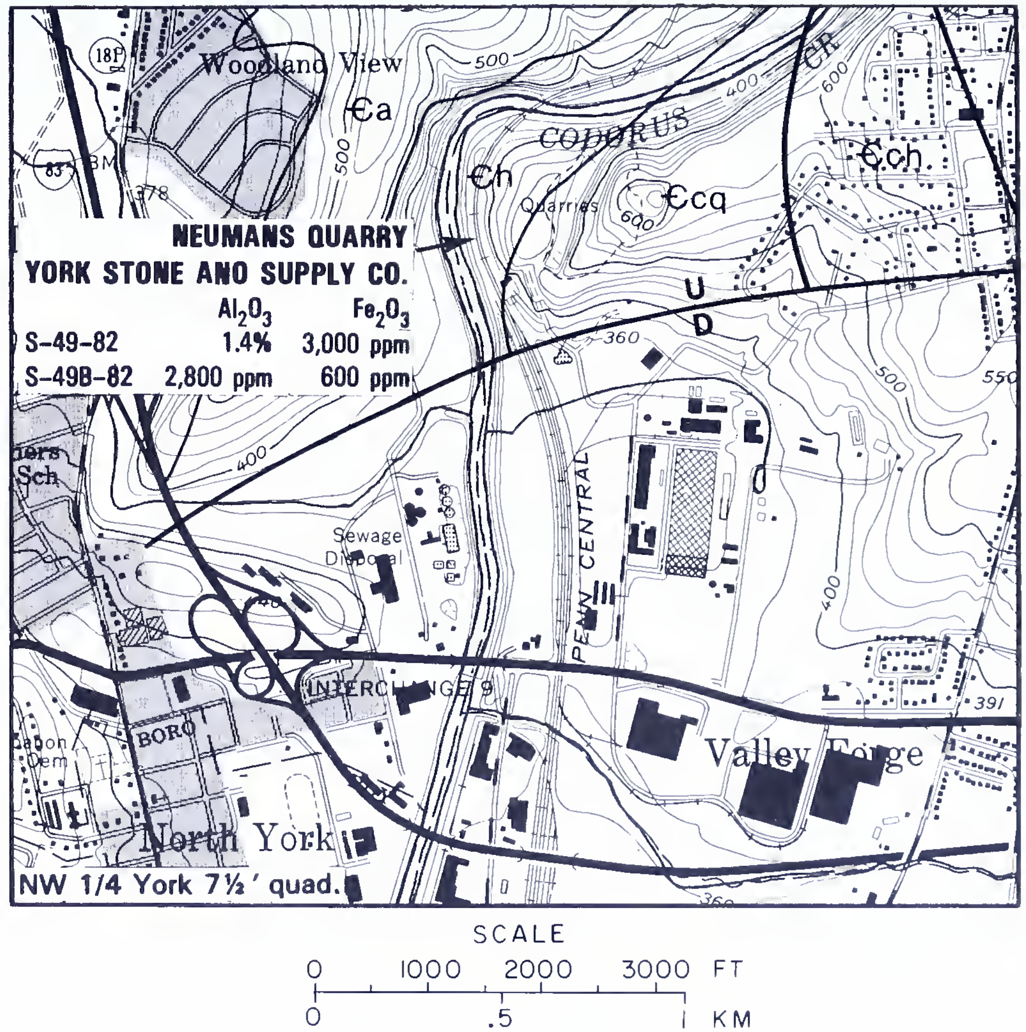
Figure 24. Geologic map showing the location of Valley Forge Stone quarry, Honeybrook Township, Chester County, samples S-46-82 and S-46B-82. Geology from Berg and Dodge (1981).



EXPLANATION

Ꞓh Harpers Formation	Ꞓch Chickies Formation

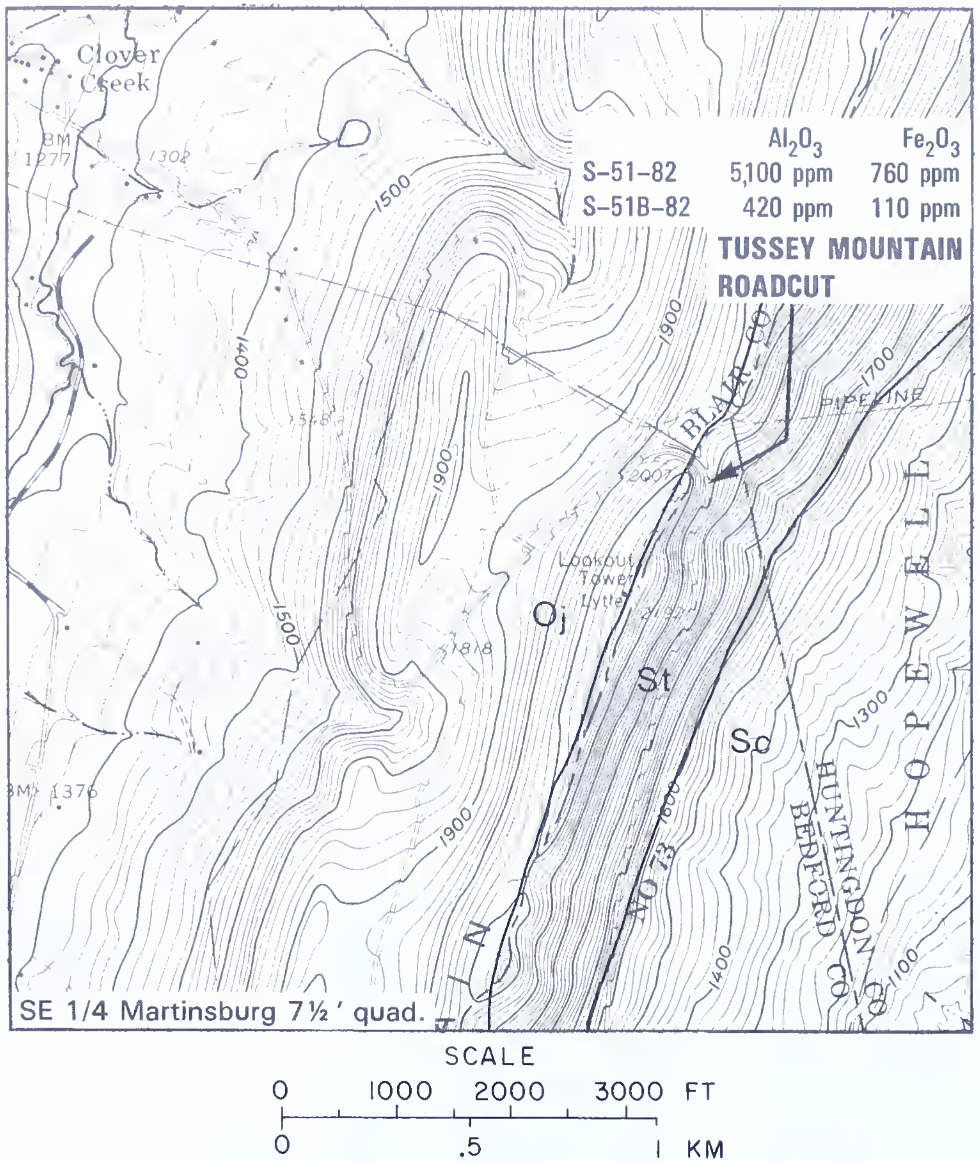
Figure 25. Geologic map showing the location of Oyster Point abandoned quarry, West Hempfield Township, Lancaster County, samples S-48-82 and S-48B-82. Geology from Berg and Dodge (1981).



EXPLANATION

Ꞓa Antietam Formation	Ꞓcq Chickies Formation, quartzite member
Ꞓh Harpers Formation	Ꞓch Chickies Formation, Hellam Member

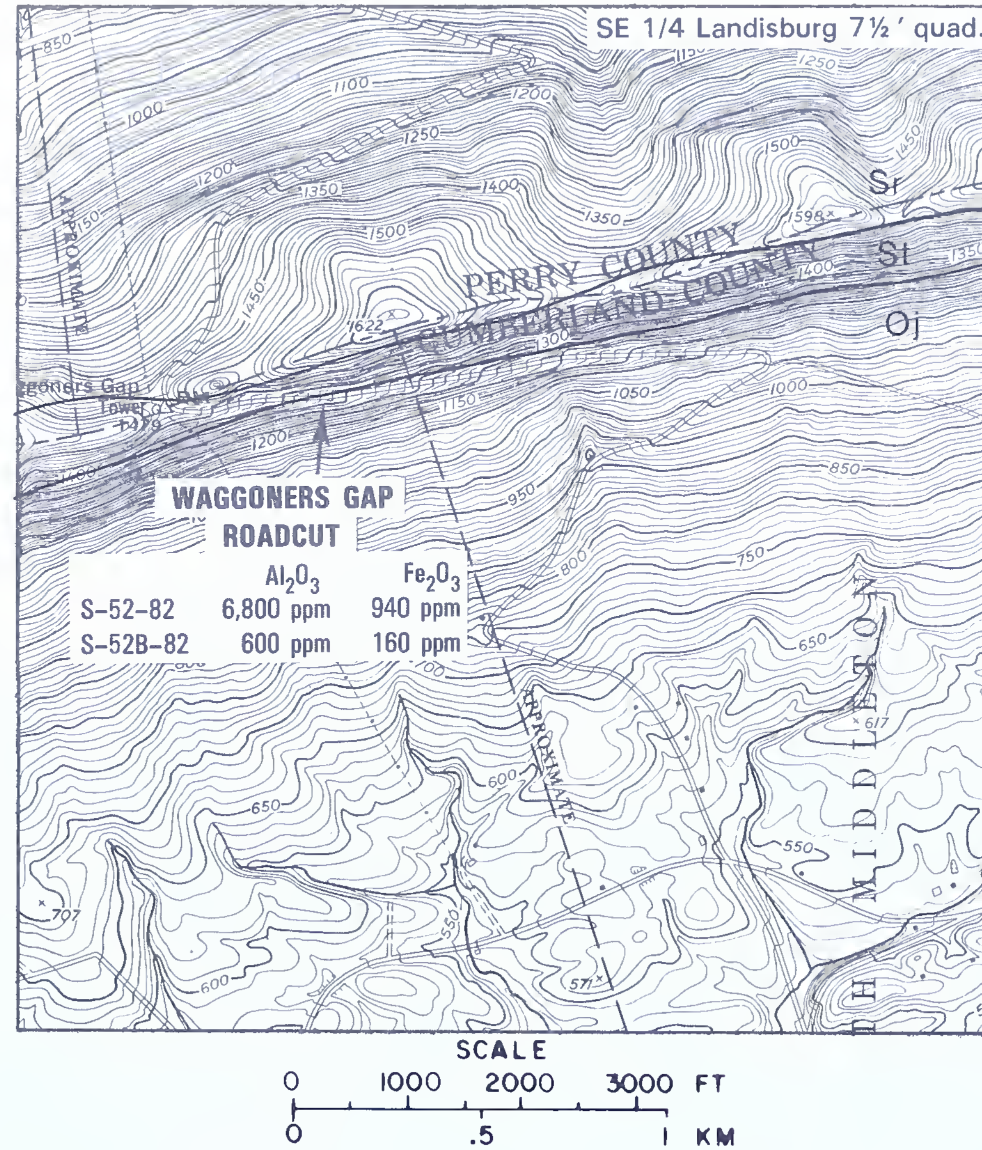
Figure 26. Geologic map showing the location of Neumans quarry, York Stone and Supply Company, Springettsbury Township, York County, samples S-49-82 and S-49B-82. Geology from Wilshusen (1979).



EXPLANATION

Sc	St	Oj
Clinton Group	Tuscarora Formation	Juniata Formation

Figure 27. Geologic map showing the location of Tussey Mountain roadcut east of Martinsburg, Liberty Township, Bedford County, samples S-51-82 and S-51B-82. Geology from Berg and Dodge (1981).



EXPLANATION

Sr	St	Oj
Rose Hill Formation	Tuscarora Formation	Juniata Formation

Figure 28. Geologic map showing the location of Waggoners Gap roadcut, Lower Frankford Township, Cumberland County, samples S-52-82 and S-52B-82. Geology from Miller (1961).

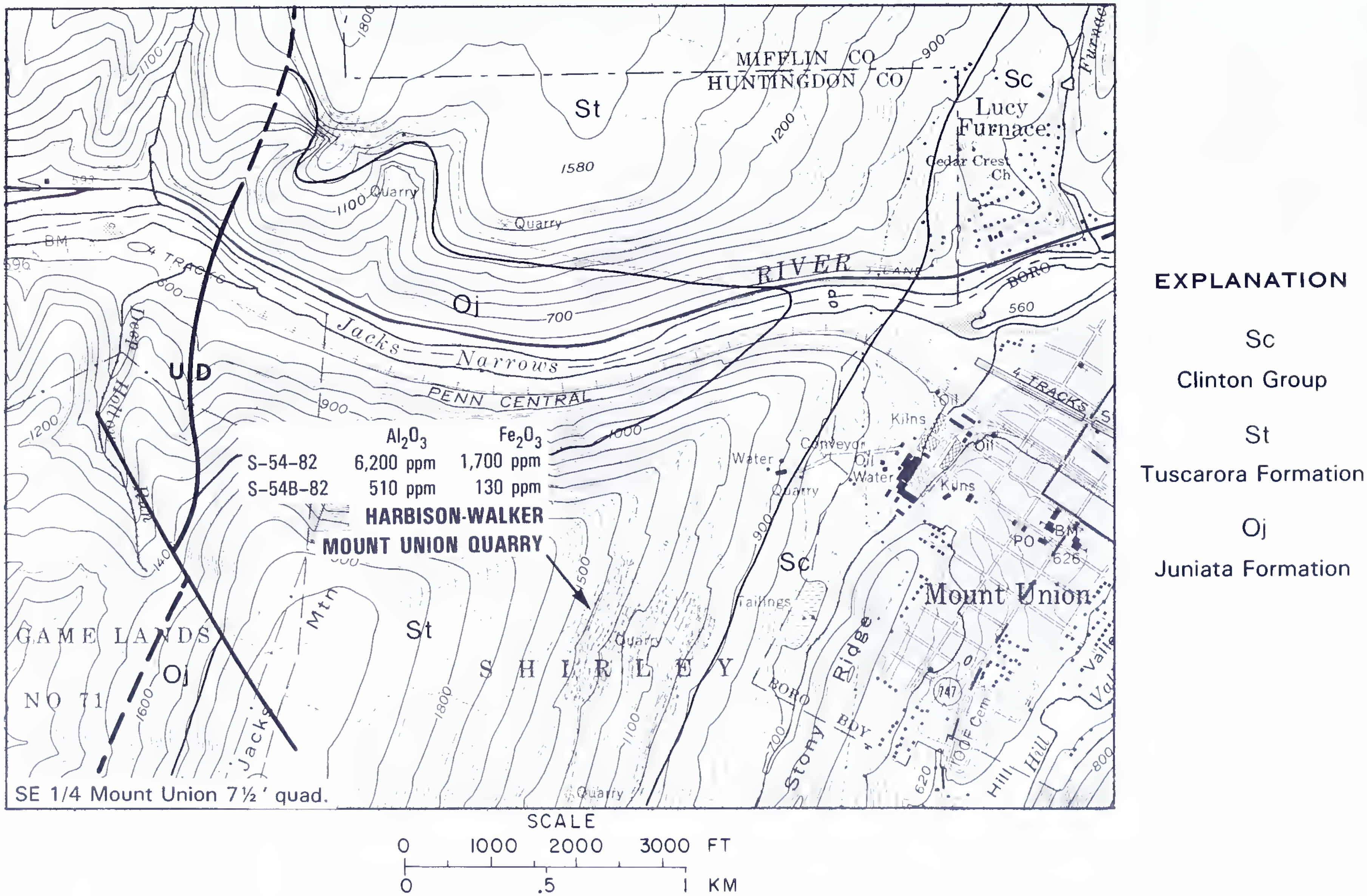
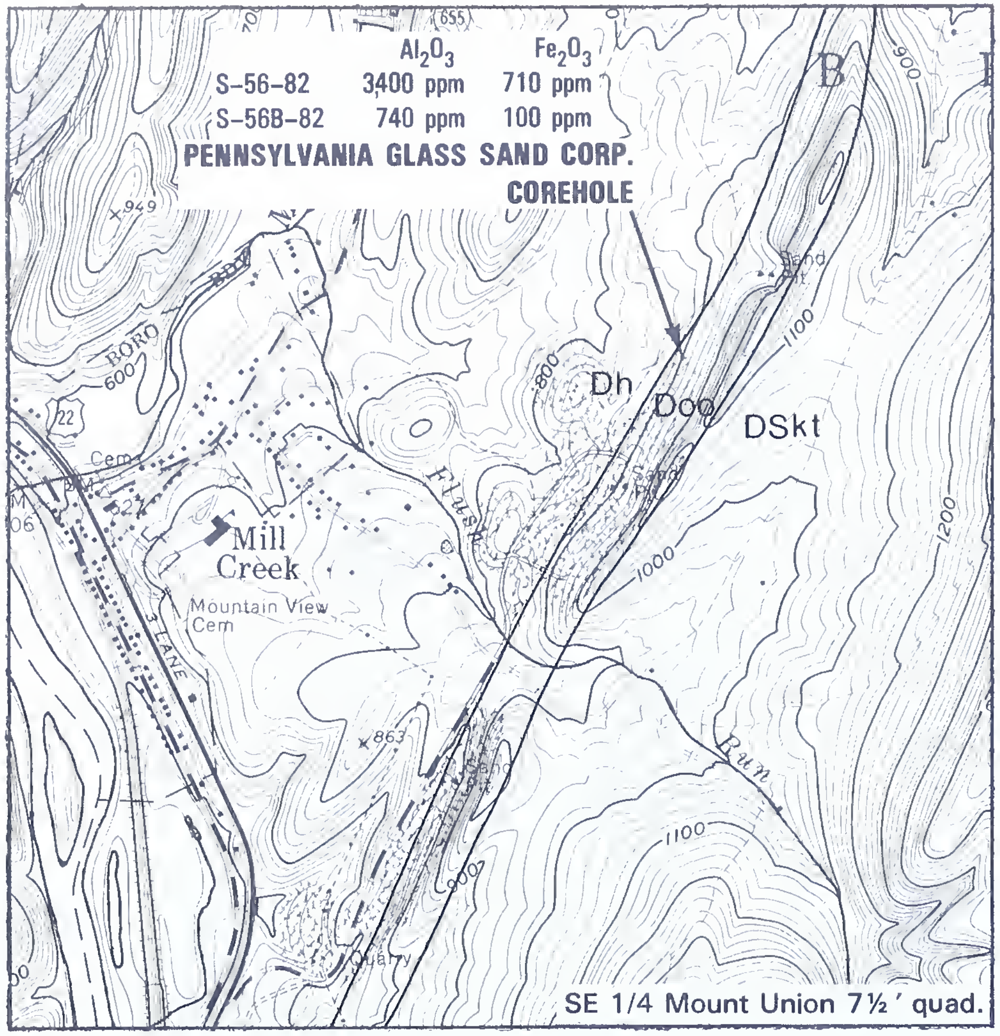


Figure 29. Geologic map showing the location of Harbison-Walker's Mount Union quarry, Shirley Township, Huntingdon County, samples S-54-82 and S-54B-82. Geology from Berg and Dodge (1981).



SCALE

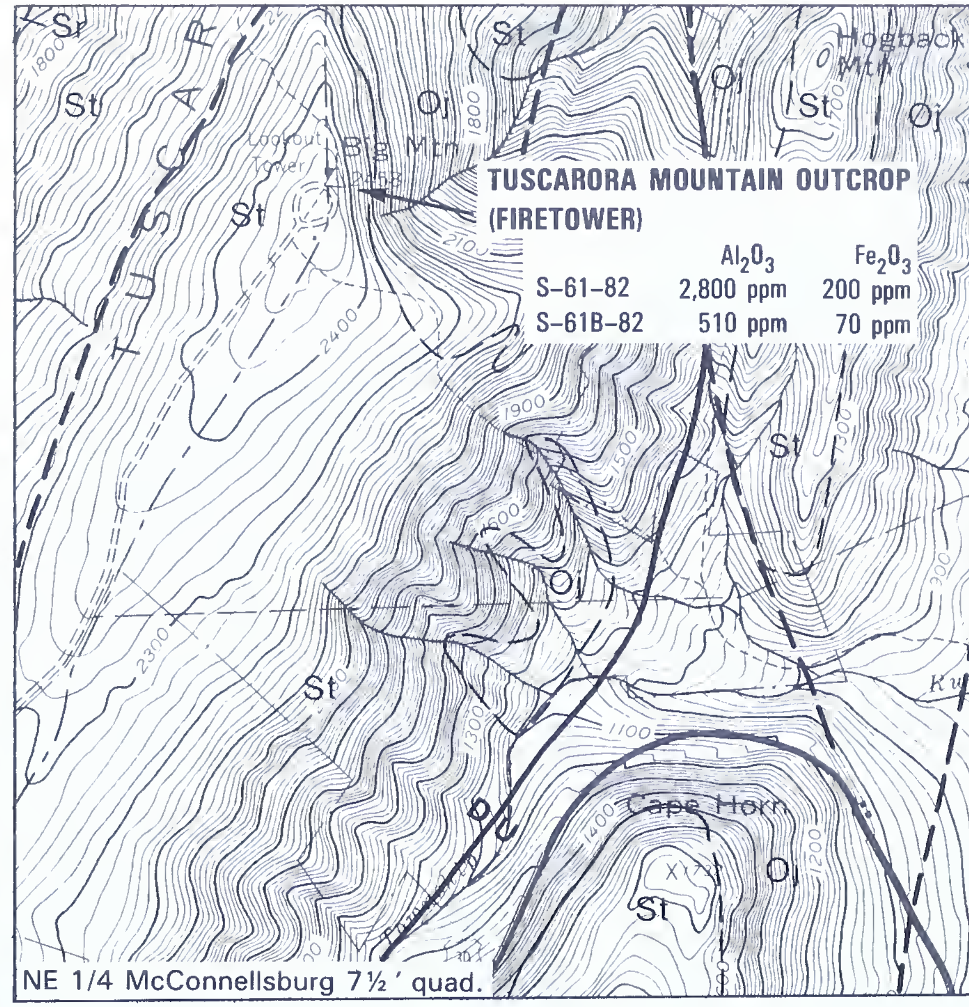
0 1000 2000 3000 FT

0 .5 1 KM

EXPLANATION

Dh	Doo	DSkt
Hamilton Group	Onondaga and Old Port Formations, undivided (includes "Oriskany")	Keyser and Tonoloway Formations, undivided

Figure 30. Geologic map showing the location of Pennsylvania Glass Sand Corporation corehole, Brady Township, Huntingdon County, samples S-56-82, S-56B-82, and S-56BB-82. Geology from Berg and Dodge (1981).



SCALE

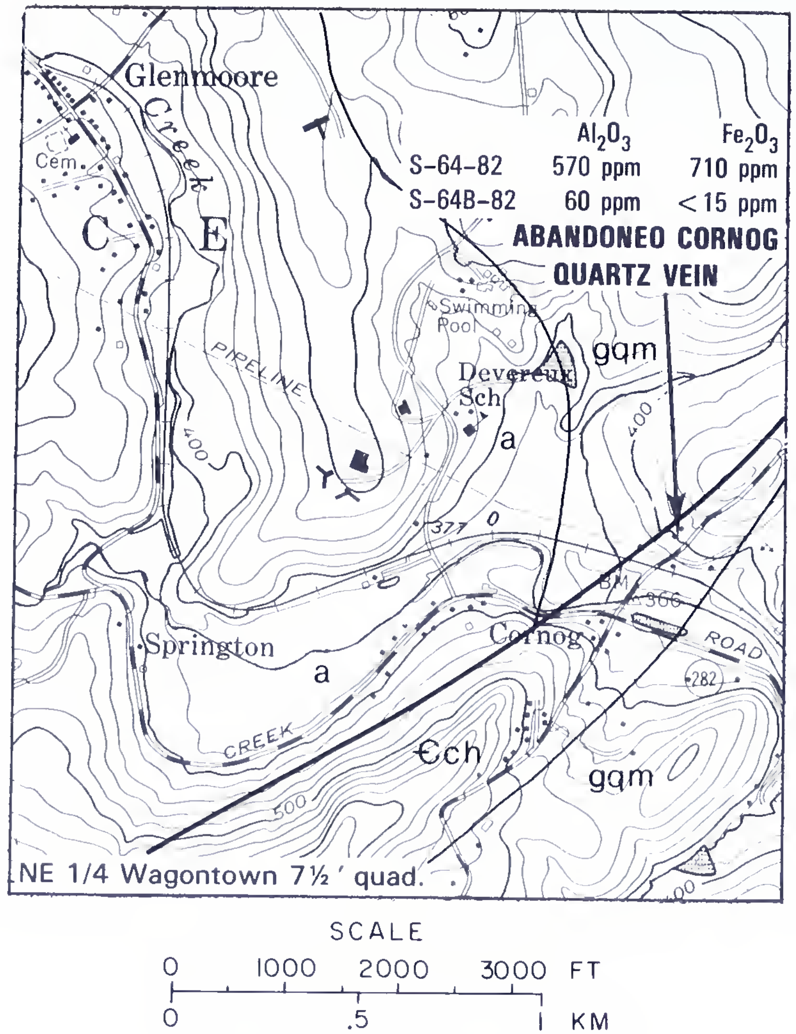
0 1000 2000 3000 FT

0 .5 1 KM

EXPLANATION

Sr	St	Oj
Rose Hill Formation	Tuscarora Formation	Juniata Formation

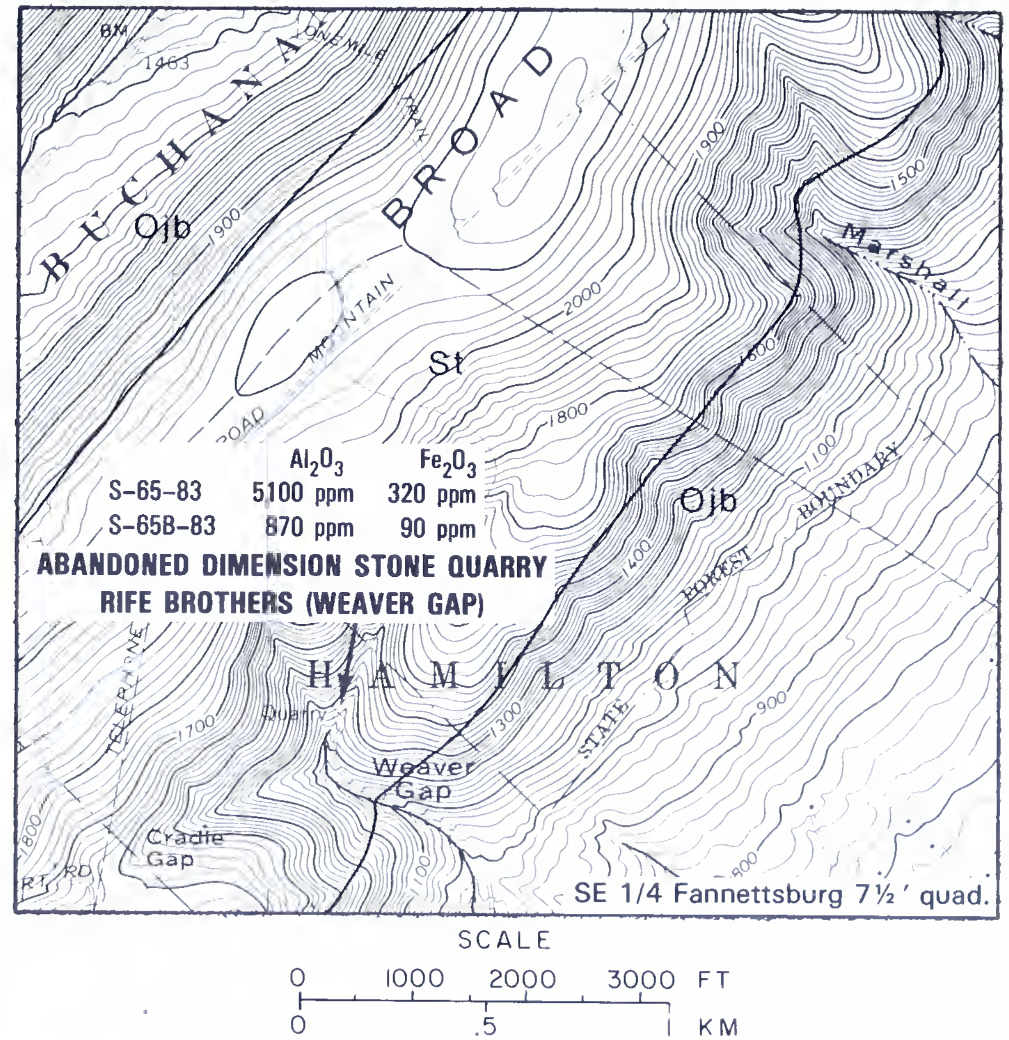
Figure 31. Geologic map showing the location of Tuscarora Mountain (Firetower) outcrop, Metal Township, Franklin County, samples S-61-82, S-61B-82, and S-61BB-82. Geology from Pierce (1966).



EXPLANATION

€ch	a	gqm
Chickies Formation	Anorthosite	Quartz monzonite and quartz monzonite gneiss

Figure 32. Geologic map showing the location of abandoned Cornog quartz vein, Wallace Township, Chester County, samples S-64-82 and S-64B-82. Geology from Berg and Dodge (1981).



EXPLANATION

St	Ojb
Tuscarora Formation	Juniata and Bald Eagle Formations, undivided

Figure 33. Geologic map showing the location of abandoned Rife Brothers dimension-stone quarry, Hamilton Township, Franklin County, samples S-65-83, S-65B-83, and S-65BB-83. Geology from Berg and Dodge (1981).

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